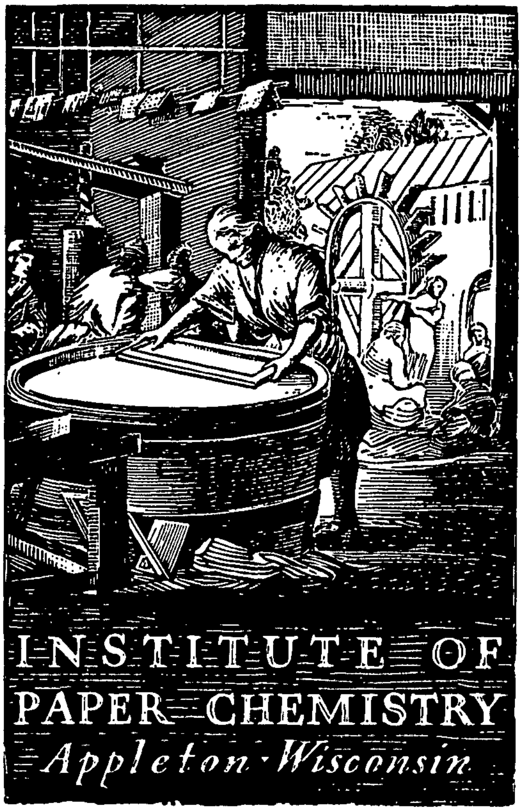

DEVELOPMENT OF MEANS FOR MEASURING THE EFFECT OF SURFACE FINISH ON PRINT QUALITY

Project 3269

Report Two
A Progress Report
to
MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

December 17, 1976

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

The purity of colors and the blackness of blacks of prints of ink on paper are always limited by the portion of the light entering the eye which has been reflected from the upper surface of the ink film. This light is essentially unmodified by the colored pigments within the ink film. The amount of this unwanted light present at the viewing angle depends upon the surface topography of the ink film which in turn is dependent upon the surface roughness of the paper, the extent to which the ink film fills this roughness, the size and shape of ink pigment particles, and the extent to which vehicle is drained from the ink pigment due to paper absorptivity. Report One of this project described the development of an instrument for measuring this unwanted surface reflection.

Measurements on prints of magenta (process red) and cyan (process blue) inks on five printing papers have shown that this instrument provides a direct measure of the degree to which color is degraded by surface reflection. Printed gloss, which is generally assumed to correlate with color quality, was shown to be an unreliable indicator. The effects of surface reflection upon color were shown to include a decrease in purity, an increase in lightness and, in the case of magenta prints, a shift in hue. The amount of surface reflection and color degradation was shown to depend strongly upon the paper used and the length of time the ink was in contact with the paper surface prior to drying.

The instrument used in these studies was adequate for establishing the utility of the measurements but was so slow in response that the number of measurements which could be made was severely limited. Therefore, a new direct reading

instrument has been designed and constructed. This new instrument is suitable for more detailed studies for refining the understanding of the ways in which paper and ink-paper interactions affect color. It is also suitable for routine evaluation of paper for quality color printing. Such a test would supplant printed gloss measurements which have been shown to be unreliable for this purpose. Where only such routine measurements are needed a somewhat simplified instrument would suffice.

INTRODUCTION

This report is divided into three parts covering three distinct steps in the investigation. Part I describes the use of the polarizing reflectometer* of Report One to investigate the color changes due to surface reflection for a series of prints of ink on paper. This work demonstrated that the amount of surface reflection can be related directly to the visual importance of the color degradation and that the properties of the paper have an important effect upon the extent of this degradation. In contrast, printed gloss and "paper surface efficiency" (PSE) were not reliable properties for predicting color degradation. This work also showed that this original instrument was too slow for extensive research work or for routine use. The research data obtained were studied to determine ways that the measurements could be abridged in the interest of developing a more practical instrument.

Part II describes the design and construction of a new instrument. Since this instrument is designed to provide direct digital values for both the internal (surface) and total reflectances it has been called a direct reading polarizing reflectometer.

Part III describes preliminary measurements which have been made with this new direct reading instrument. Additional studies using the new instrument are in progress and will be reported later.

*Even though this instrument provides responses from which color characteristics are calculated it is called a reflectometer rather than a colorimeter in deference to those (1) who believe that the latter term should be restricted to instruments which provide color characteristics directly.

I. COLORIMETRIC STUDIES WITH THE POLARIZING REFLECTOMETER OF REPORT ONE

PAPERS AND PRINTS

The five papers selected for initial study are described in Table I. Solid prints were made using the Vandercook proof press. An offset blanket laminated to a magnesium support was used as the printing plate in order to simulate the ink coverage attainable by the offset process. The actual amount of ink transferred to the paper was determined gravimetrically. Ultraviolet curing magenta and cyan inks (Suncure Web Process Red and Blue) were used. Prints were either dried immediately with radiation from a 220 watt/inch Hanovia ultraviolet lamp or allowed to stand for 24 hours and then dried in the same manner. The characteristics of the prints are summarized in Table II in the Appendix.

Figure 1 is a plot of the hue and grayness of the magenta prints, as calculated from color density measurements, on the GATF Color Circle diagram. It is clear that these prints vary in color in the same manner as the magenta prints investigated by Preucil (2). The cyan prints are not plotted because the red sensitivity of the available densitometer was inadequate for making the necessary measurements.

COLOR MEASUREMENTS

CIE tristimulus values, $\underline{X}$, $\underline{Y}$, and $\underline{Z}$ were obtained for the external (or surface) and internal components of reflected light and for the total reflected light and are denoted by the subscripts $\underline{E}$, $\underline{I}$, and $\underline{T}$, respectively.

Measurements were made at 15°, 30°, 45°, 60°, and 75° incidence for magenta prints on Papers 1, 2, and 5; at 30°, 45°, and 60° for magenta prints on

TABLE I

DESCRIPTION OF PAPERS

Code	Type	75° Gloss, %	K & N Reflectance, %	PSE[a]	Luminous Reflectance,[b] %	Purity[b]	Dominant[b] Wavelength, nm
1	Cast coated	76	48	53	82.6	2.4	564.4
2	Dull coated	22	63	37	86.4	2.5	576.1
3	Embossed coated	25	57	33	86.6	2.6	576.2
4	Glossy coated	68	66	62	85.8	2.7	576.1
5	Uncoated	4.1	35	9	78.6	5.3	574.1

[a] $$\text{PSE} = \frac{\text{Gloss} + (100 - \text{absorptivity})}{2}$$

where absorptivity = 1 1/3 $(100 - R_{KN})$.

[b] Determined with the standard brightness tester.

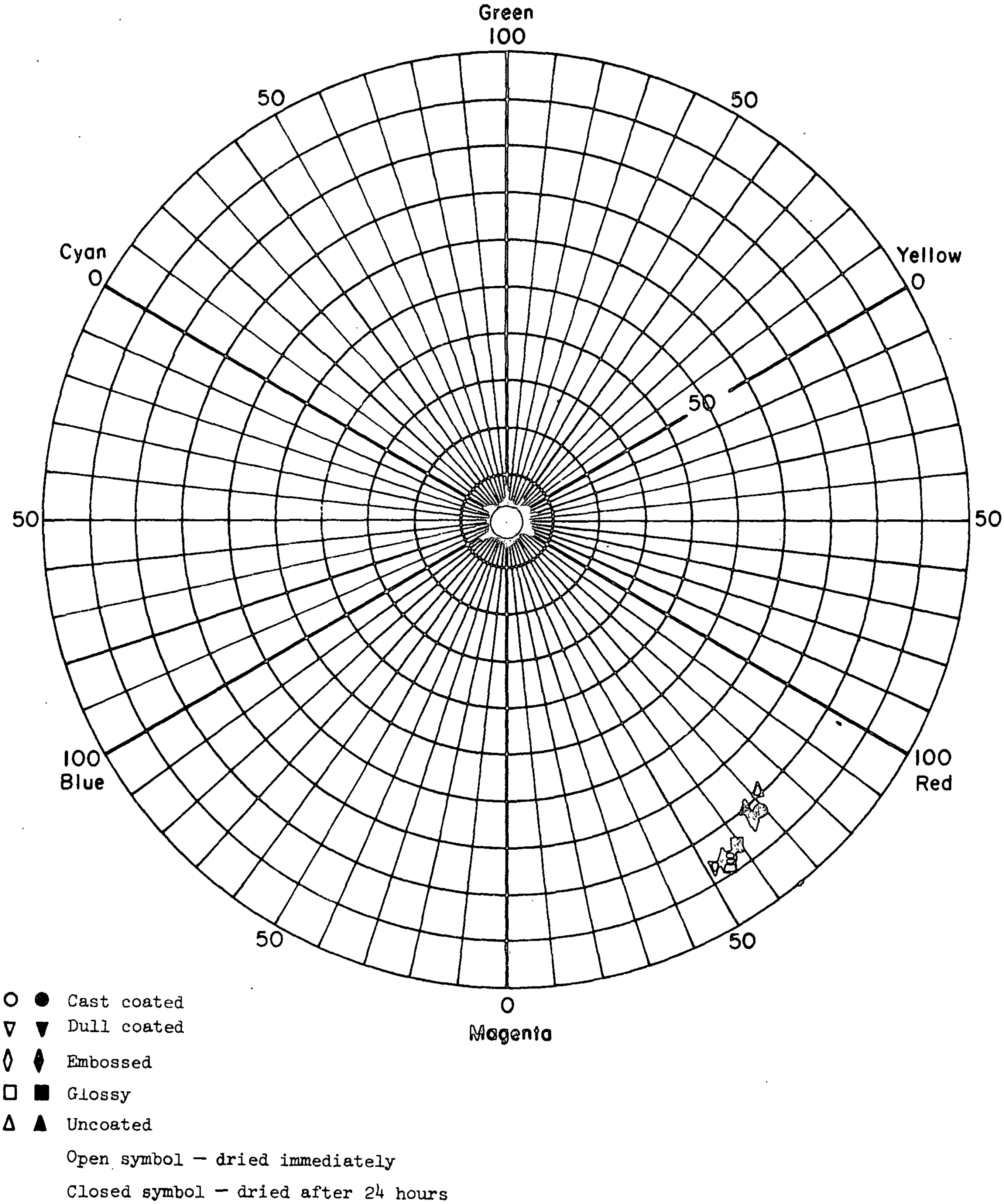

Figure 1. Hue and Grayness of Magenta Prints

Papers 3 and 4; and at 45° only for cyan prints. The colorimetric data, for 45° incidence only, are summarized in Table III in the Appendix. The corresponding colorimetric data for the same samples, determined with the Standard Brightness Tester equipped with appropriate filters for the measurement of the tristimulus values (Illuminant C) are also included. The Standard Brightness Tester is, of course, not able to distinguish between internal and external components and provides data derived from the total reflected light flux. Figures 2 and 3 compare the luminous reflectance, $\underline{Y}_{\underline{T}}$, and the purity $\underline{P}_{\underline{T}}$, of the total reflected light flux of the magenta prints, as determined with the polarizing reflectometer, with the corresponding values obtained with the brightness tester. Although a linear relationship exists, the luminous reflectance values obtained with the polarizing reflectometer are slightly lower and the purity is somewhat higher. These are differences that might be expected in view of the much smaller cone angles of the polarizing reflectometer for both illumination and viewing. Similar plots for the cyan prints, which are shown as Fig. 4 and 5, reveal greater discrepancies. This may be due in part to differences in instrument colorimetric responses. However, photoconductor memory was particularly troublesome when measuring the cyan prints so it is possible that real equilibrium values were not always attained. Nevertheless the fact that both instruments detect similar differences between samples justifies the tentative use of these colorimetric data.

In the CIE chromaticity diagram an additive mixture of two light fluxes falls on the straight line joining the individual components. Therefore this diagram is useful for illustration of the manner in which the internal and external components of reflected light combine to form the stimulus which is responsible for the color observed. Figure 6 includes CIE plots for magenta prints dried immediately and after 24 hours on Papers 1 (cast coated), 2 (dull coated) and 5

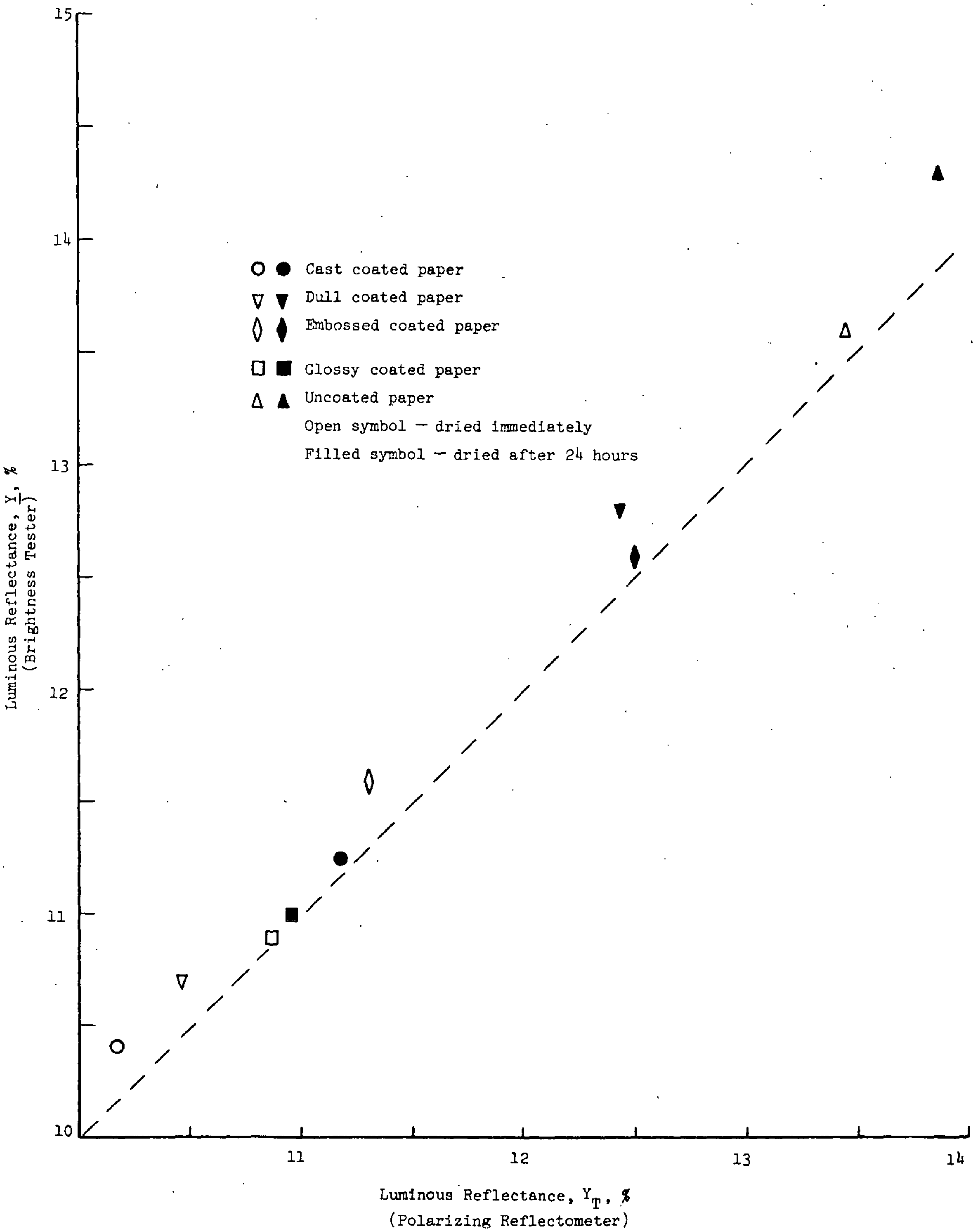

Figure 2. Magenta Print Luminous Reflectance. Comparison of Polarizing Reflectometer with the Brightness Tester

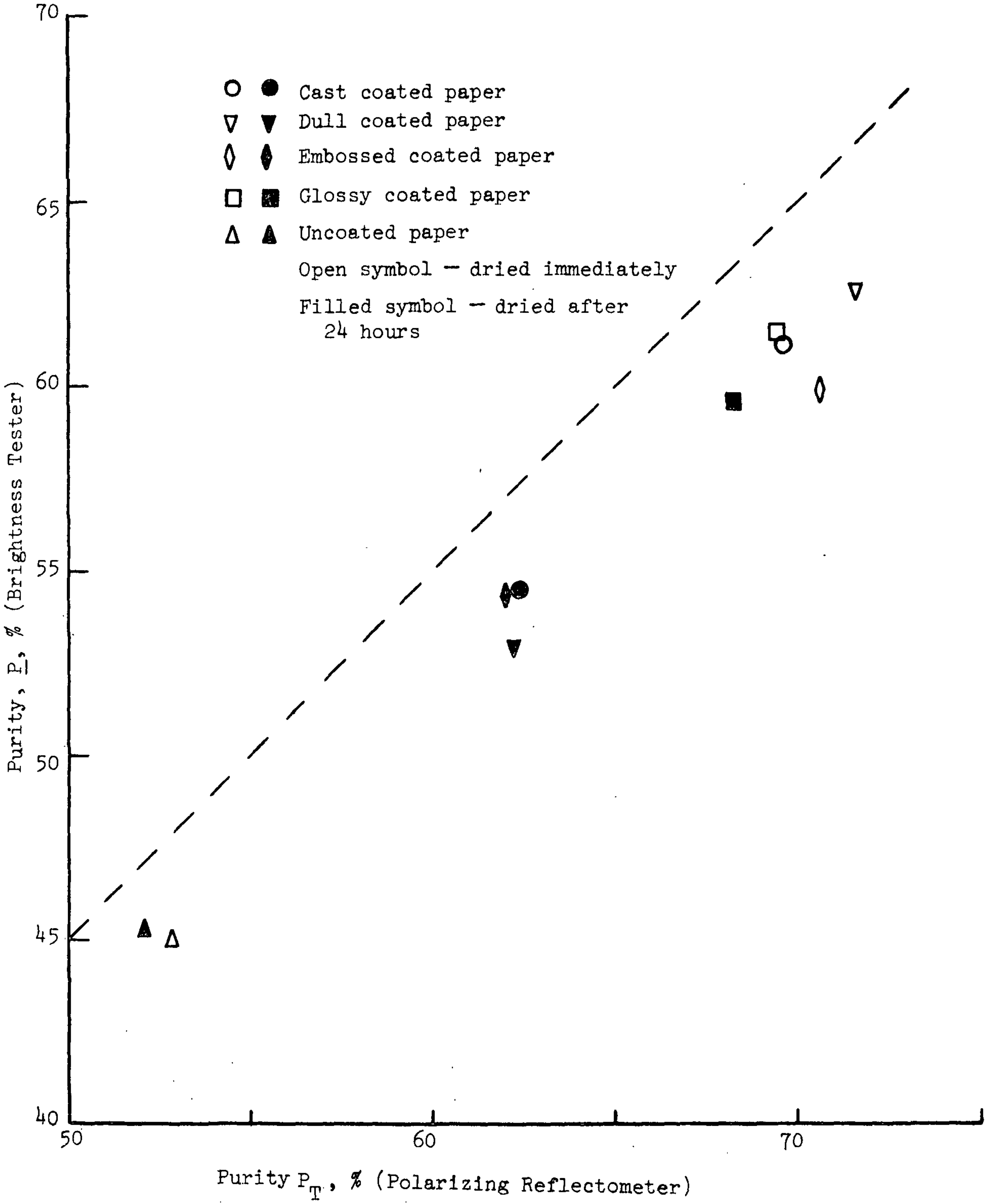

Figure 3. Magenta Print Purity. Comparison of Polarizing Reflectometer with the Brightness Tester

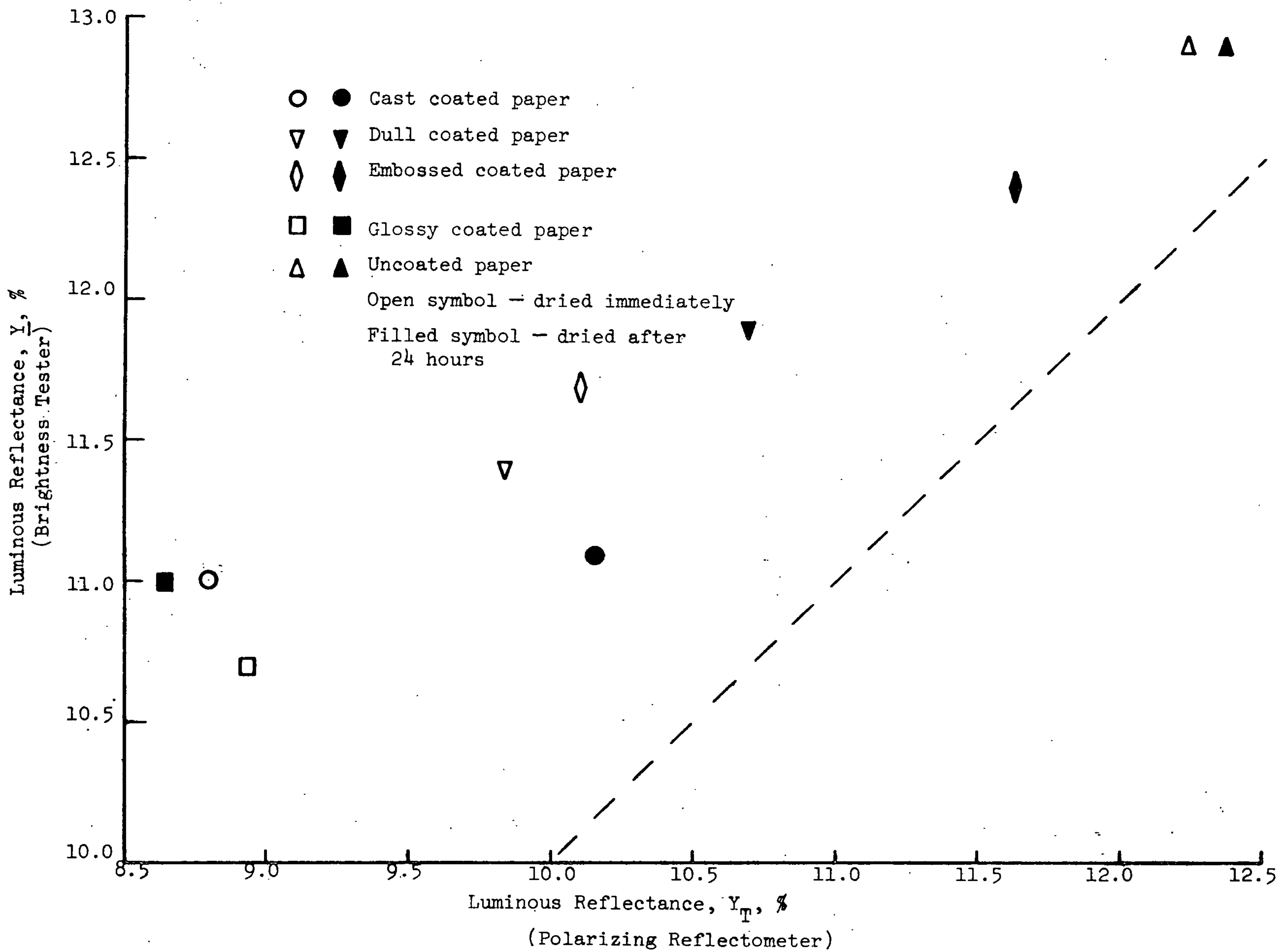

Figure 4. Cyan Print Luminous Reflectance. Comparison of Polarizing Reflectometer with the Brightness Tester

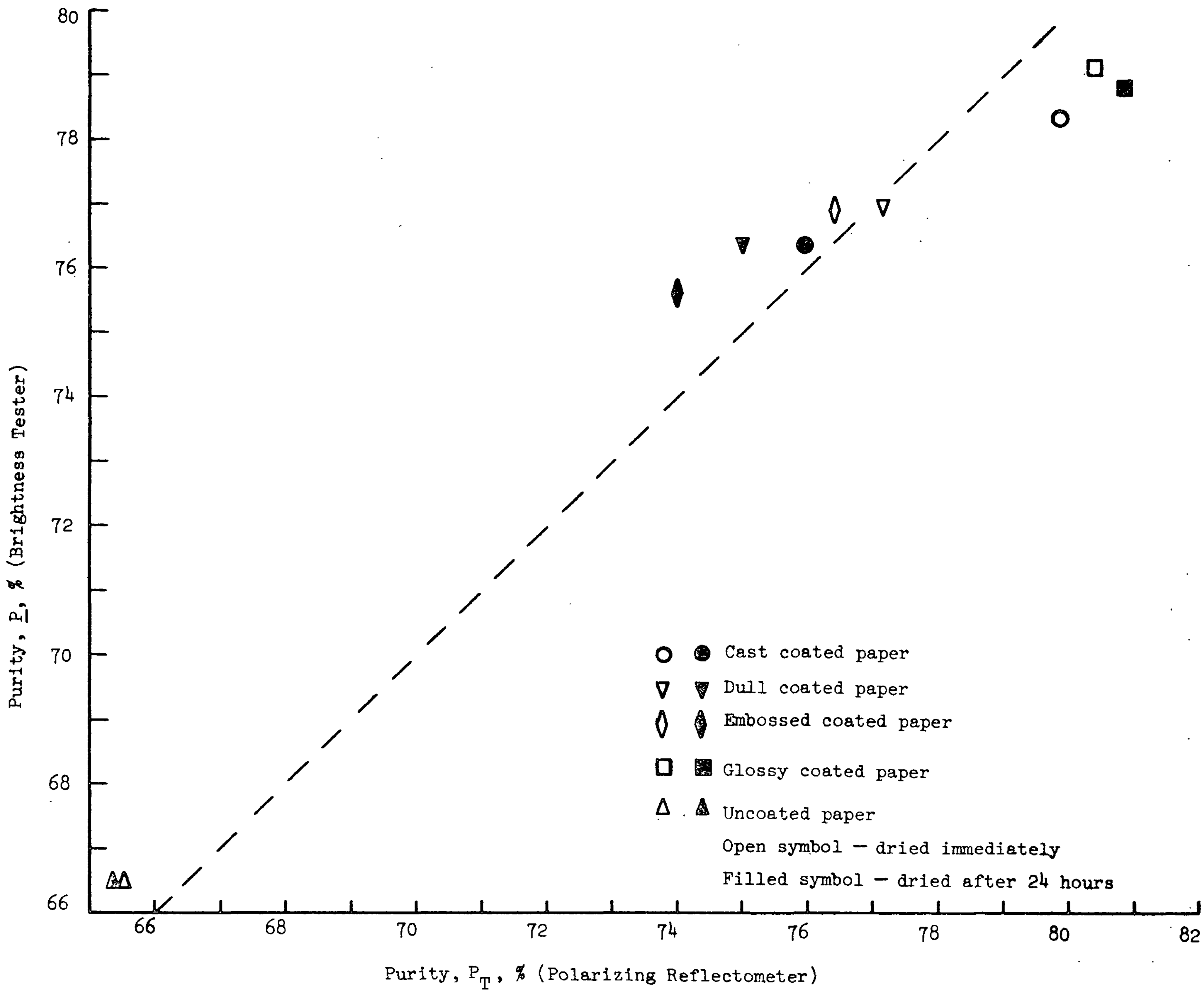

Figure 5. Cyan Print Purity. Comparison of Polarizing Reflectometer with the Brightness Tester

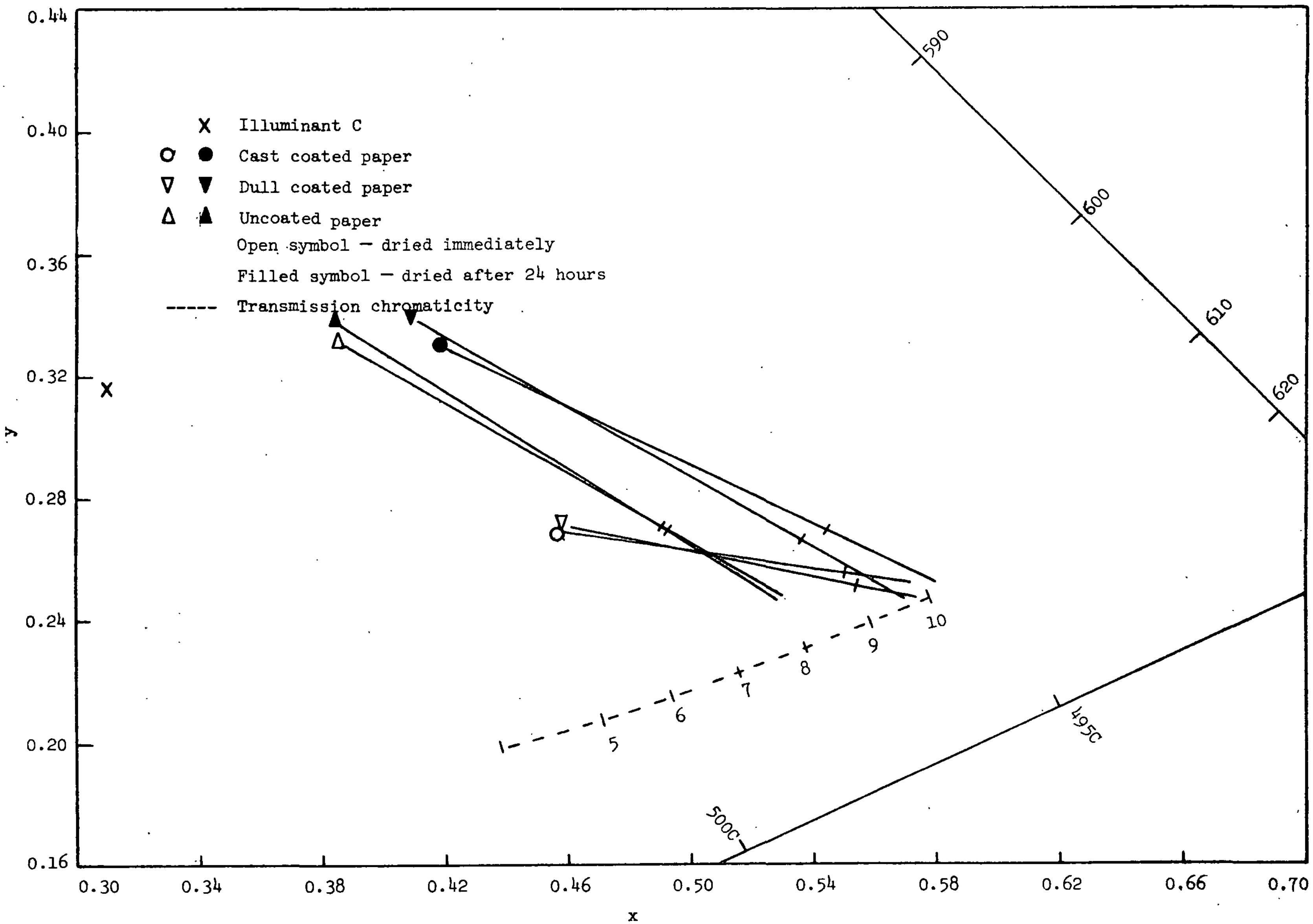

Figure 6. Chromaticity Diagram for Selected Magenta Prints. The External Component is Located by the Identifying Symbol for the Paper. The Internal Component is Located at the Unmarked End of the Connecting Line. The Total Chromaticity is Denoted by the Cross Line Segment

(uncoated). Data for Papers 3 and 4 have been omitted to avoid crowding. In each case the external component lies at the end of the line marked by the identifying symbol and the internal component lies at the other end of the line. The total reflected light is located by the small cross line segment. It is noteworthy that the internal component chromaticities for all prints on coated papers are closely spaced and would have substantially the same chromaticity except for the degrading effect of the external component. Furthermore, these internal chromaticities agree closely with those obtained by transmission measurements made with the GE Recording Spectrophotometer on dried ink films when calculated to 10 g/m^2 film weight. Transmitted color is, of course, not subject to degradation by light reflected at the first surface. Differences in chromaticities of the total light reflected by the prints are clearly due to differences in amount and quality of the light reflected from the surface. For prints on coated paper which were dried immediately after printing, the external chromaticity lies near a line passing through Illuminant C and the internal chromaticity. These external chromaticities can be ascribed to white light from which the internally reflected light has been imperfectly removed. However, for those prints which were allowed to stand for 24 hours before drying, the external reflection chromaticity corresponds to a dominant wavelength in the orange region of the spectrum. Magenta pigments commonly exhibit a yellow-orange bronze, which is a colored surface reflection due to a sudden change in refractive index at the edge of the absorption band. Bronzing becomes troublesome when there is excessive absorption of ink vehicle which leaves the pigment surface inadequately covered. The prints on uncoated paper, whether dried immediately or after 24 hours, exhibited the orange external color due to the very rapid absorption of ink vehicle by this type of stock. It seems that the hue shifts shown in Fig. 1 and the similar hue shifts reported by Preucil (2) for magenta prints are due to bronzing.

It is noteworthy that the chromaticity of the internal component reflected by the magenta print on uncoated paper, as shown by Fig. 6, is quite different from those of the four coated papers. Therefore, not all of the color difference between the prints on coated and uncoated papers can be attributed to the external component. It is believed that substantially all of the ink pigment lies on top of the coated surface and that absorption by the coated paper is limited to the ink vehicle. The internal component was therefore transmitted through the same quantity of ink pigment on all the coated surfaces. In contrast, the absorption of ink into the larger pores of the uncoated paper carries some ink pigment beyond scattering centers of the paper. Consequently some light is scattered before it encounters the full quantity of pigment in the printed ink film.

A similar chromaticity diagram for cyan prints is shown as Fig. 7. Because of the closer spacing of the chromaticities of cyan prints only the prints on cast coated and uncoated paper are included.

EFFECT OF ANGLE OF INCIDENCE

The Fresnel reflection increases with increasing angle of incidence but because of the greater separation from the specular angle the portion of the total reflectance at 0° due to the surface component decreases with increasing angle of incidence. There is a small increase in purity of the internal component which may be attributed to the longer path length of the light in the ink film. This, combined with the greater relative portion of internal component, leads to the general increase in purity of the total reflected light at high angles of incidence that is illustrated by Fig. 8.

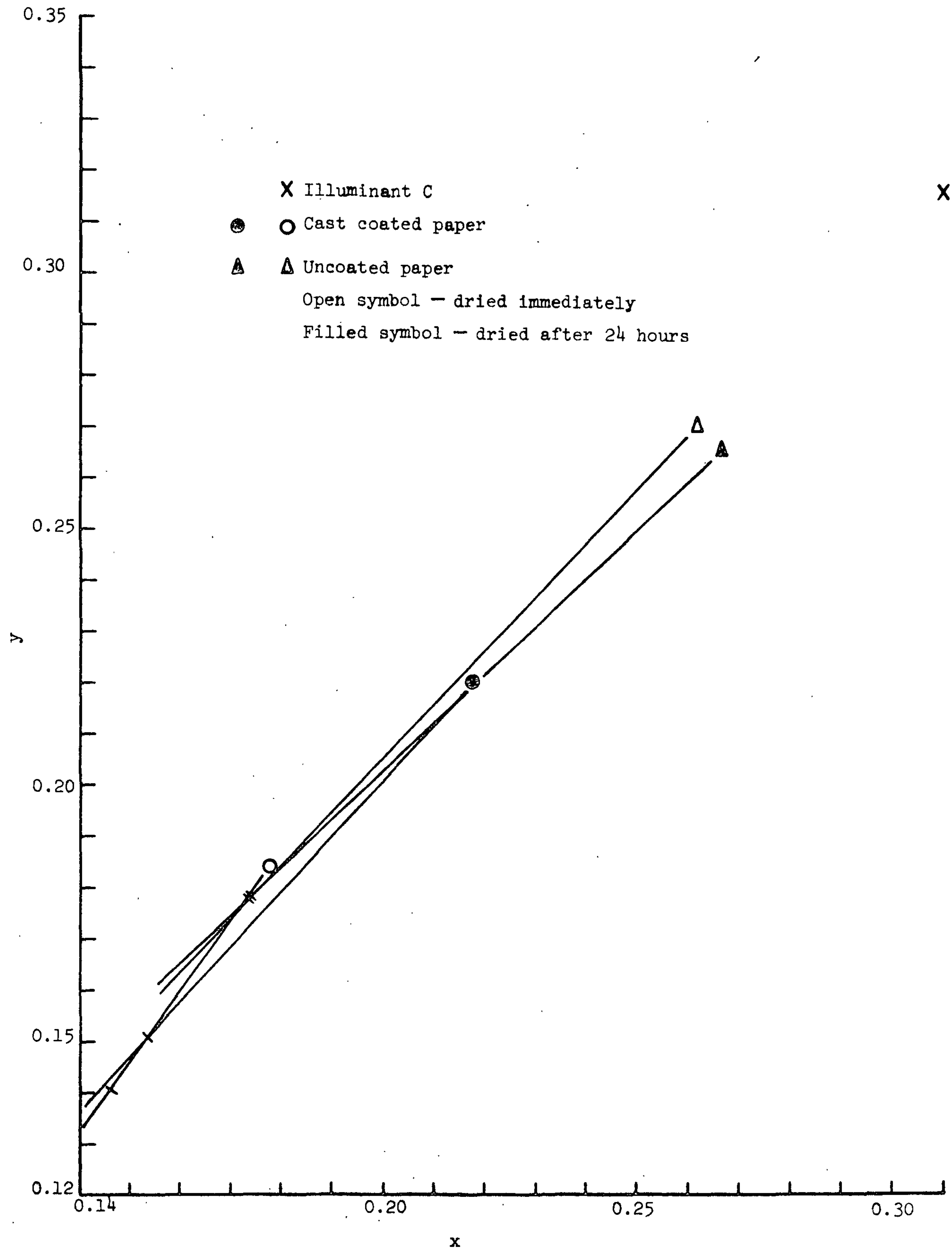

Figure 7. Chromaticity Diagram for Selected Cyan Prints. The External Component is Located by the Identifying Symbol for the Paper. The Internal Component is Located at the Unmarked End of the Connecting Line. The Total Chromaticity is Denoted by the Cross Line Segment

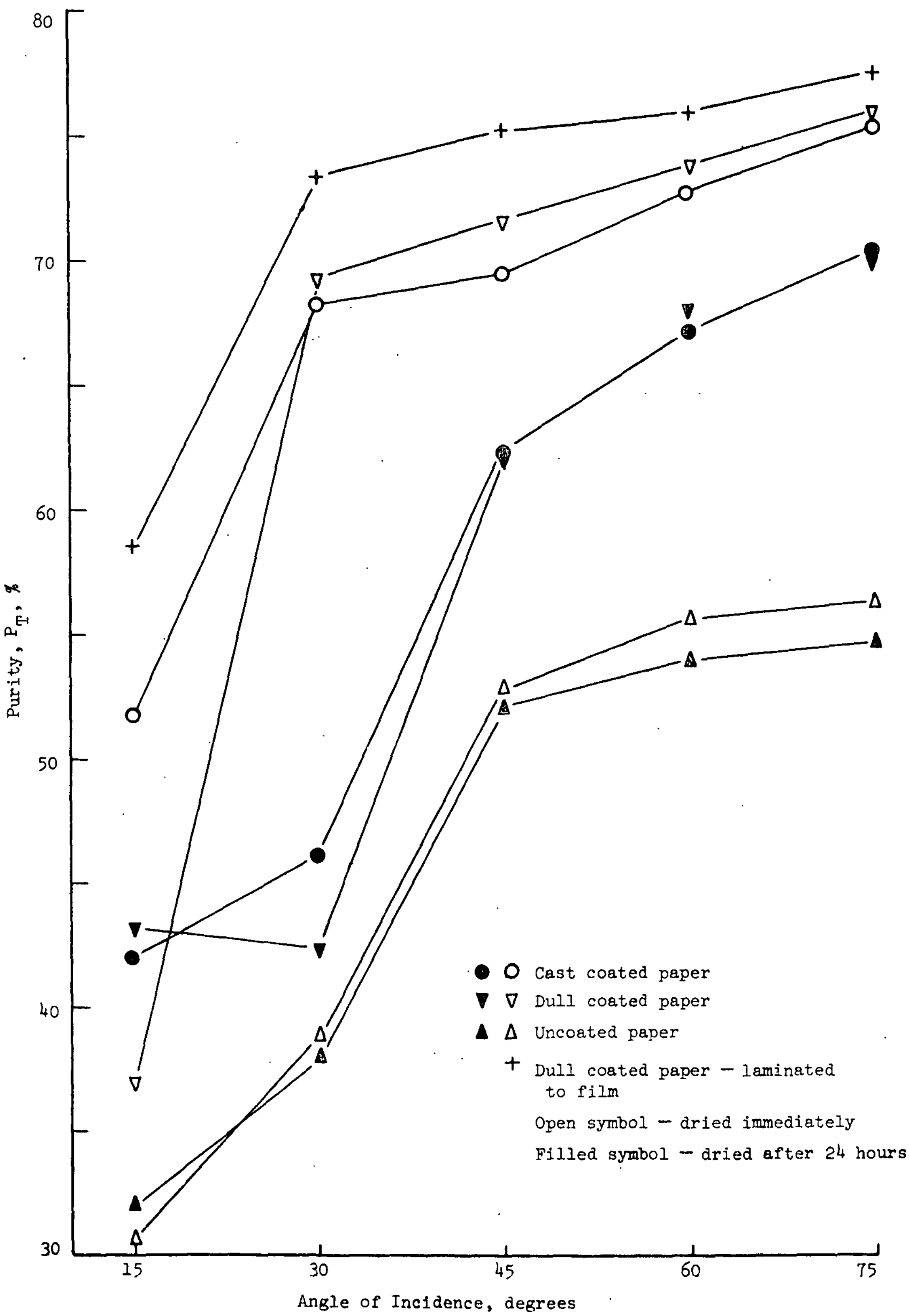

Figure 8. The Effect of Angle of Incidence Upon the Total Reflection Purity of the Magenta Prints

The light available for measurement decreased considerably with increasing angle of incidence and this somewhat increased the scatter of the data. This decrease in light can be accounted for by the increased spreading of the incident beam over a greater area and increased Fresnel reflection with increasing incident angle. Both of these factors decrease the intensity of light entering the ink film and limit the effectiveness of illumination from high angles of incidence. For any reflectance measurement made with a broad incident cone angle, the value obtained will be weighted more heavily with the contribution of the light from the lower incident angles and therefore will not be the true reflectance at the nominal incident angle.

In general the measurements made at the other incident angles do not add much to the information obtained at 45°. One exception is that the print on cast coated paper (Paper 1) had lower purity than the print on dull coated paper (Paper 2) at 30° to 75° incidence but greater purity at 15° incidence (see Fig. 8).

MEANS OF PREDICTING COLOR DEGRADATION

The object of this research is to provide a test method that will be indicative of the extent to which external reflection degrades the color of prints which can be used routinely to evaluate the suitability of papers for quality printing where maximum saturation is required. Such a test should provide an easily determinable single number.

The chromaticity diagram shows the relative amount of the three tristimulus excitations located as $\underline{x}$, $\underline{y}$ coordinates or by purity and dominant wavelengths. A third value is needed to locate the color in 3 dimensional color space and $\underline{Y}$, the luminous reflectance, is ordinarily used for this purpose. The external reflection increases the luminous reflectance, decreases the purity and may change the dominant wavelength. The difference between any two points in color space may be expressed as ΔE which is the distance between the points in color space measured in units which are perceptible steps of visual color difference between the two colors. The particular color difference calculated by the Institute's "Chroma" computer program is that of Friele, MacAdam and Chickering (3) as modified by Romon and Hung (4) to make it symmetrical. This modification makes the difference between two colors independent of which is used as the standard, i.e., $\Delta E_{A-B} = \Delta E_{B-A}$. The color difference ΔE_{I-T} provides a measure of the effect of the external reflection upon color in terms of the visual importance of this degradation. However, ΔE_{I-T} would not be a suitable quantity for routine use since full colorimetric data are required for calculation.

The color change represented by ΔE_{I-T} will include changes in luminous reflectance, $Y_T - Y_I = Y_E$, purity, $P_I - P_T$, and possibly in dominant wavelength, $D\lambda_I - D\lambda_T$, which are the dimensions ordinarily used to locate colors in CIE color space. Figures 9, 10 and 11 are plots for the magenta prints of the change in each of these directions against ΔE_{I-T}. Figures 12, 13 and 14 are similar plots for the cyan prints. It is evident that both Y_E and $P_I - P_T$ change in a regular manner with ΔE_{I-T} for both sets of prints. $D\lambda_I - D\lambda_T$ increases less regularly with ΔE_{I-T} for the magenta prints and shows no consistant behavior for the cyan prints. It should be emphasized that these plots provide no firm information concerning the magnitude of the component of ΔE in any of these directions. They are presented to show that either Y_E or $P_I - P_T$ correlates with ΔE_{I-T}. CIE color space is not visually uniform so there is no reason to expect these plots to be linear or to expect plots of the same property for prints of different colors to be of the same shape. The figures show the best quadratic fit to the data points. Since either Y_E or $P_I - P_T$ appear to be equally indicative as emperical measures of the color change

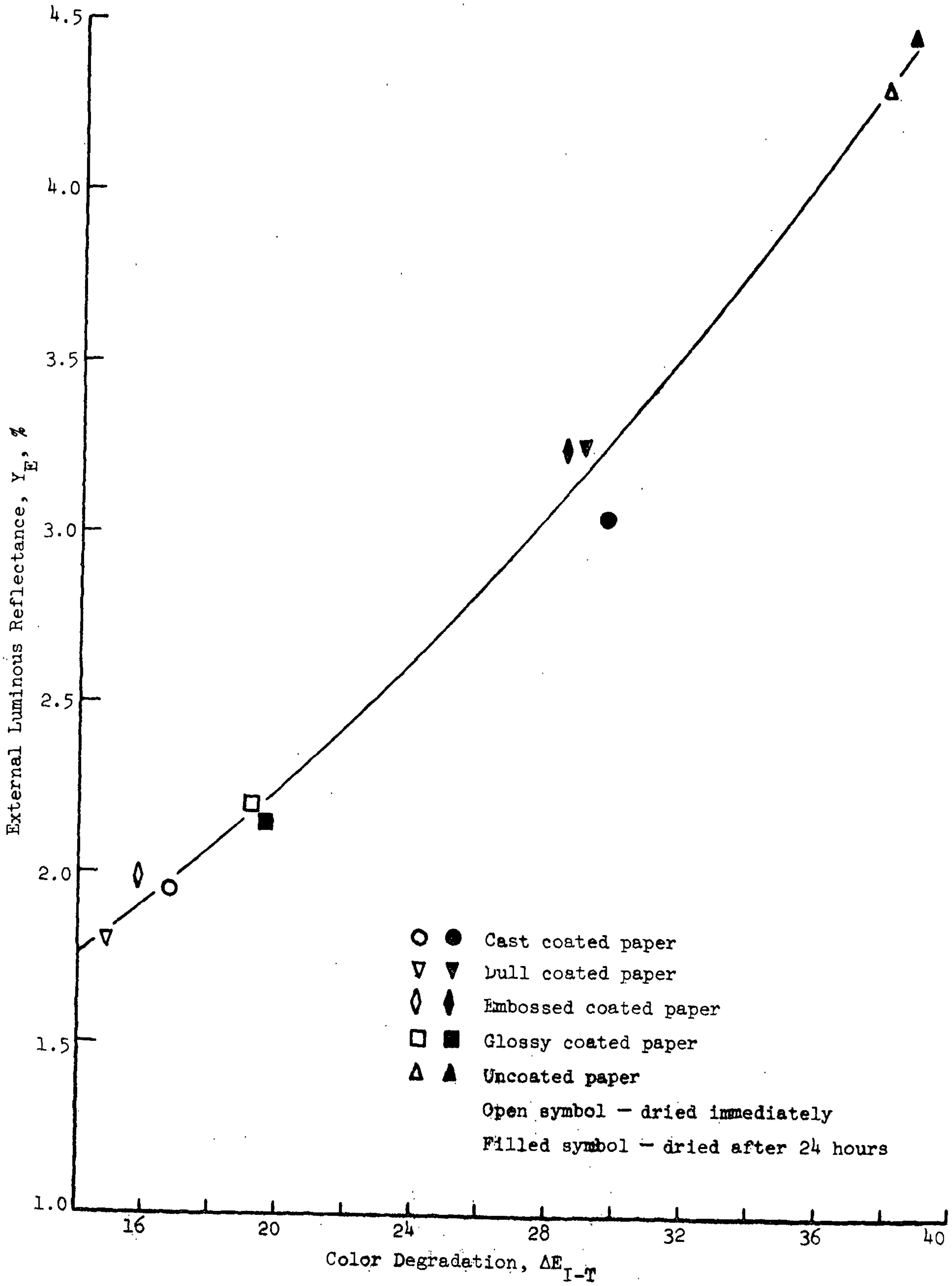

Figure 9. Correlation Between the External Luminous Reflectance, Y_E and the Color Degradation, ΔE_{I-T} for Magenta Prints

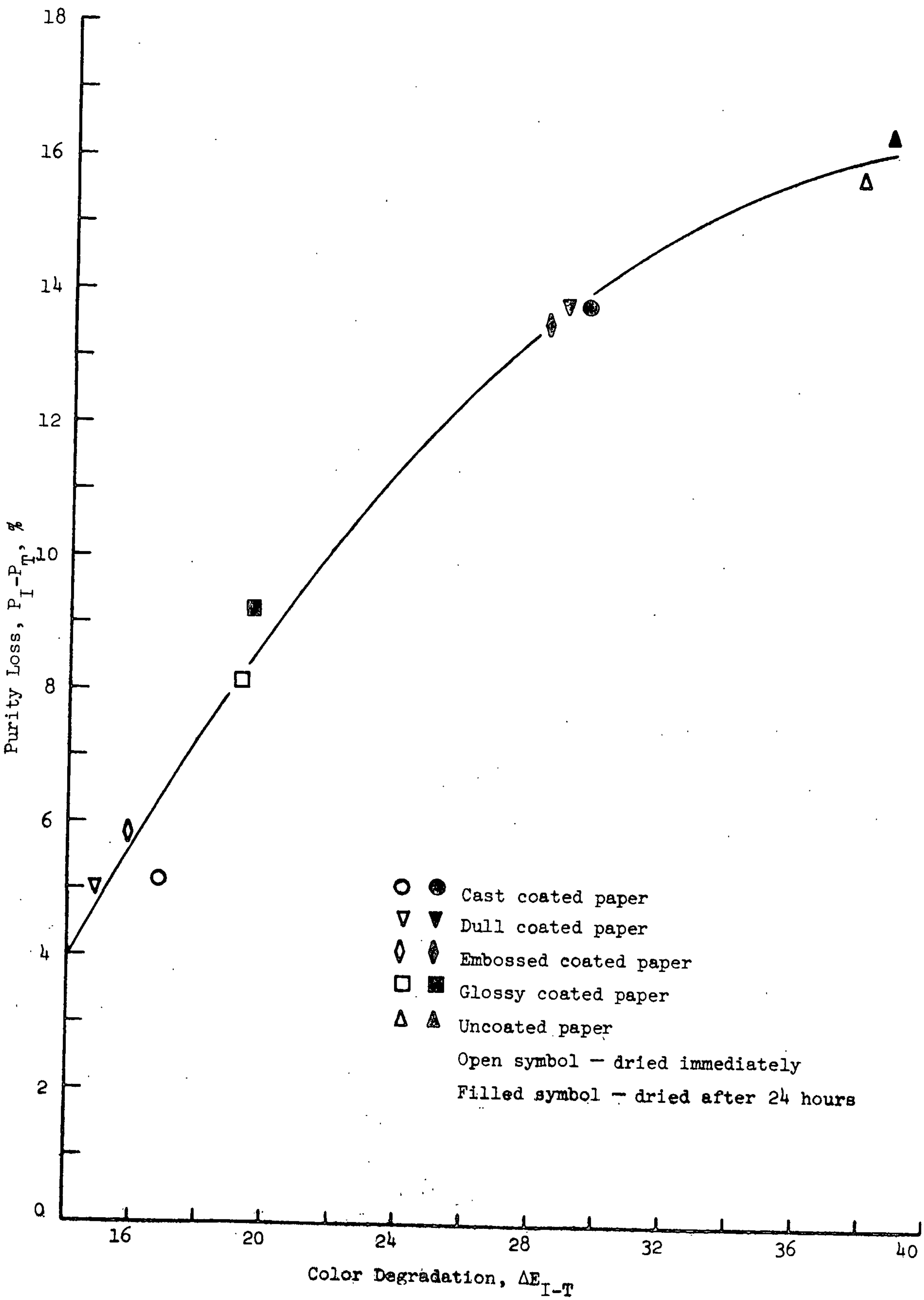

Figure 10. Correlation Between the Purity Loss, $P_I - P_T$, and the Color Degradation, ΔE_{I-T}, for Magenta Prints

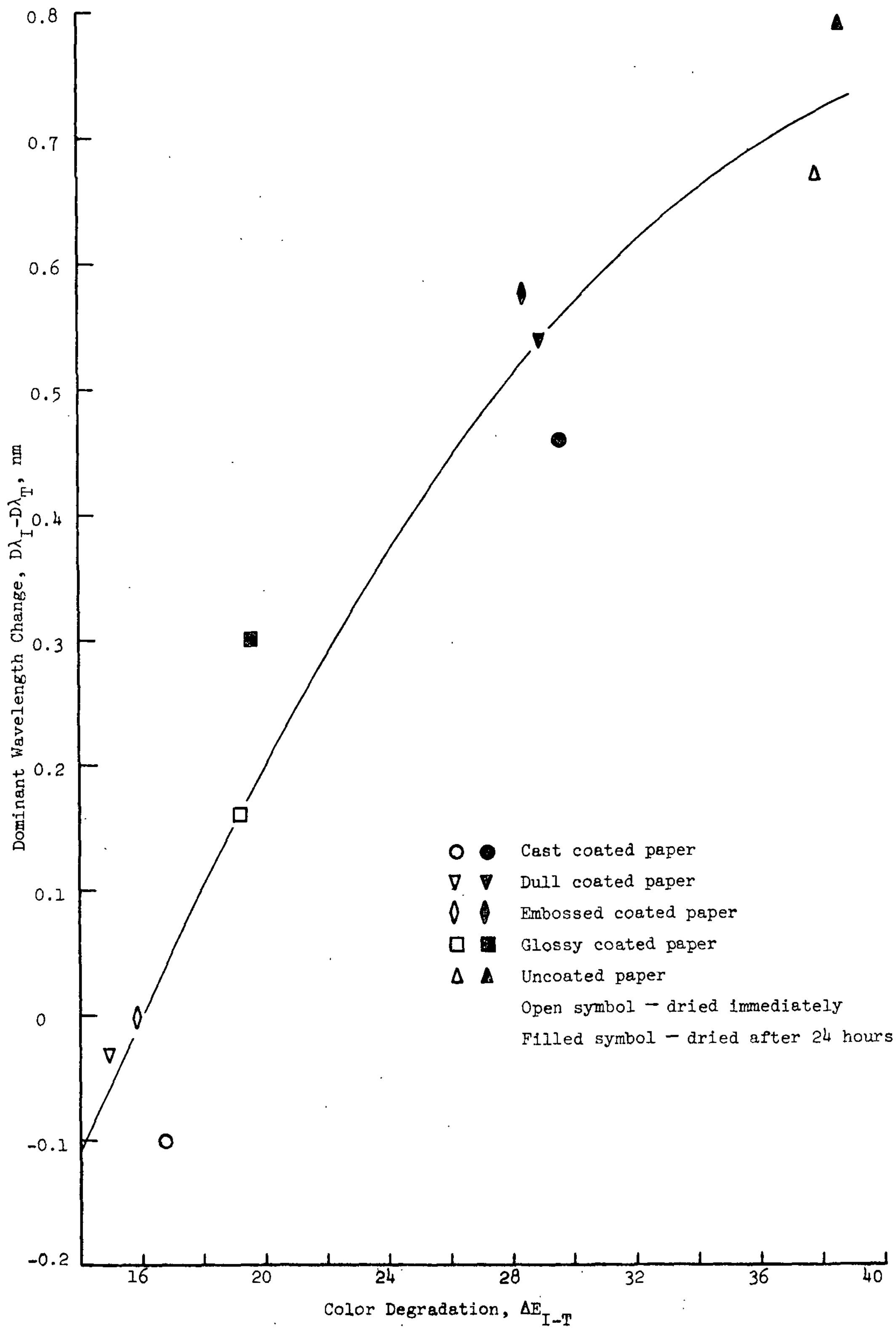

Figure 11. Correlation Between the Change in Dominant Wavelength, $D\lambda_I - D\lambda_T$, and the Color Degradation, ΔE_{I-T}, for the Magenta Prints

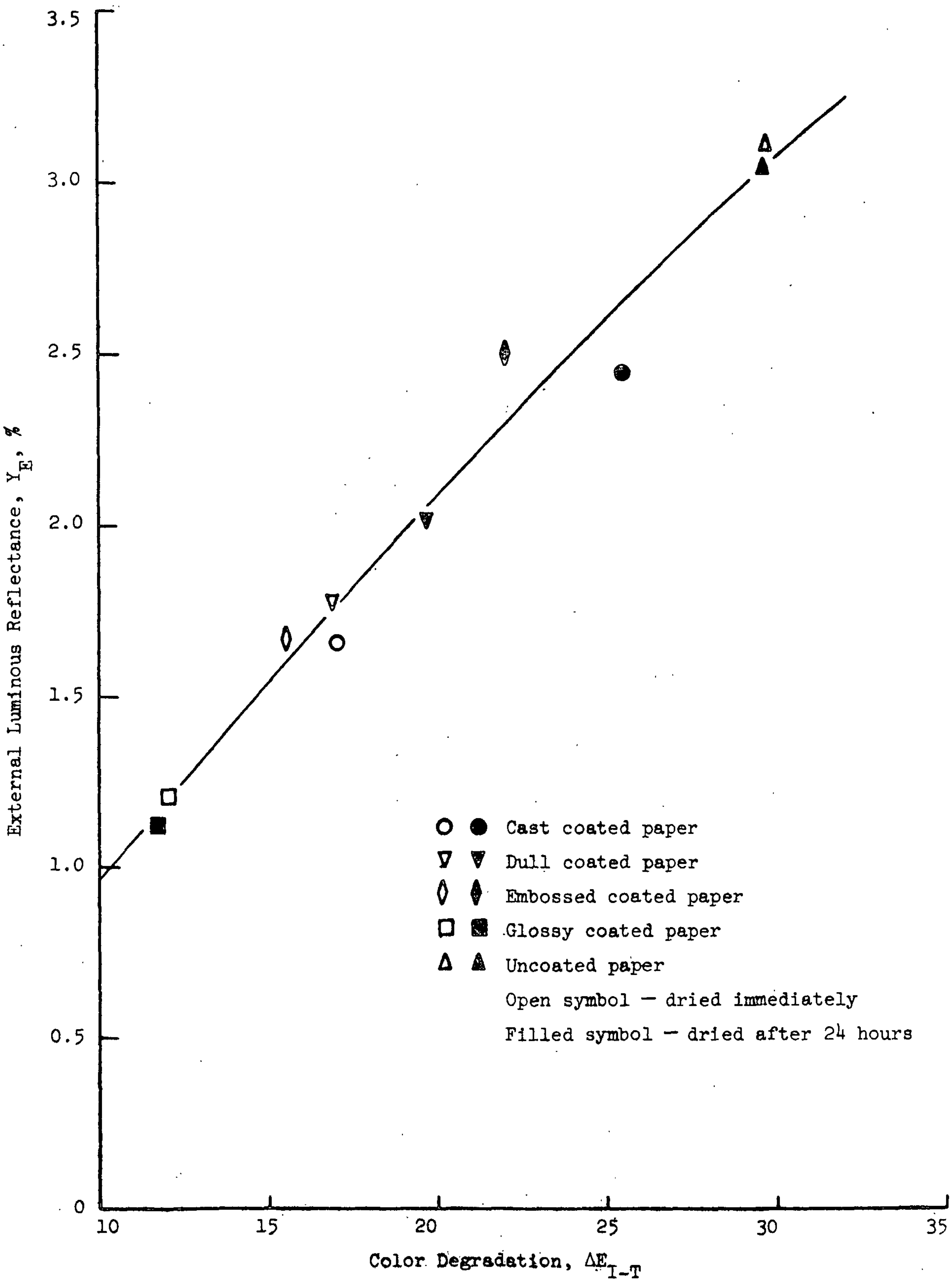

Figure 12. Correlation Between the External Luminous Reflectance Y_E and the Color Degradation, ΔE_{I-T}, for Cyan Prints

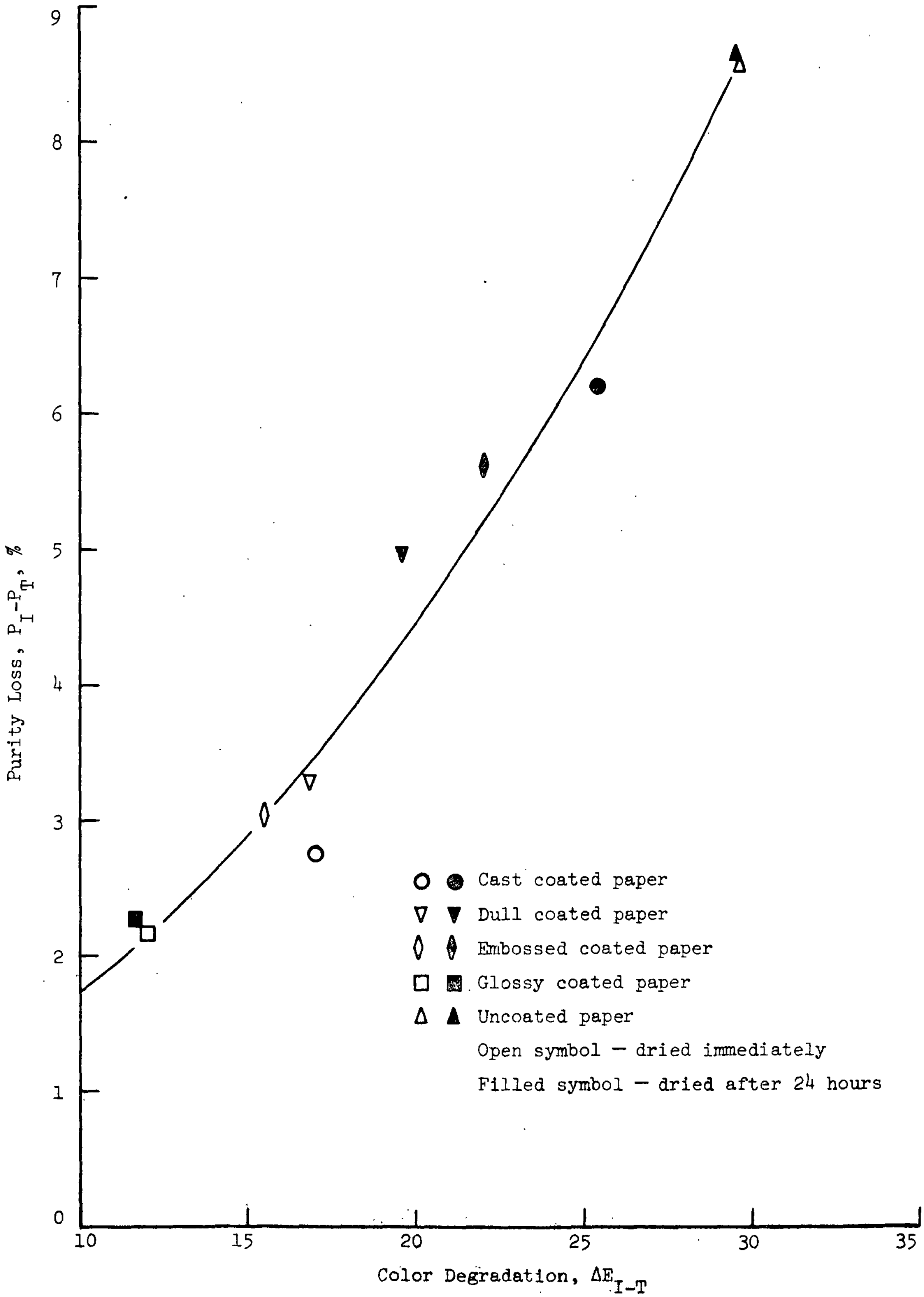

Figure 13. Correlation Between the Purity Loss, P_I-P_T, and the Color Degradation ΔE_{I-T} for Cyan Prints

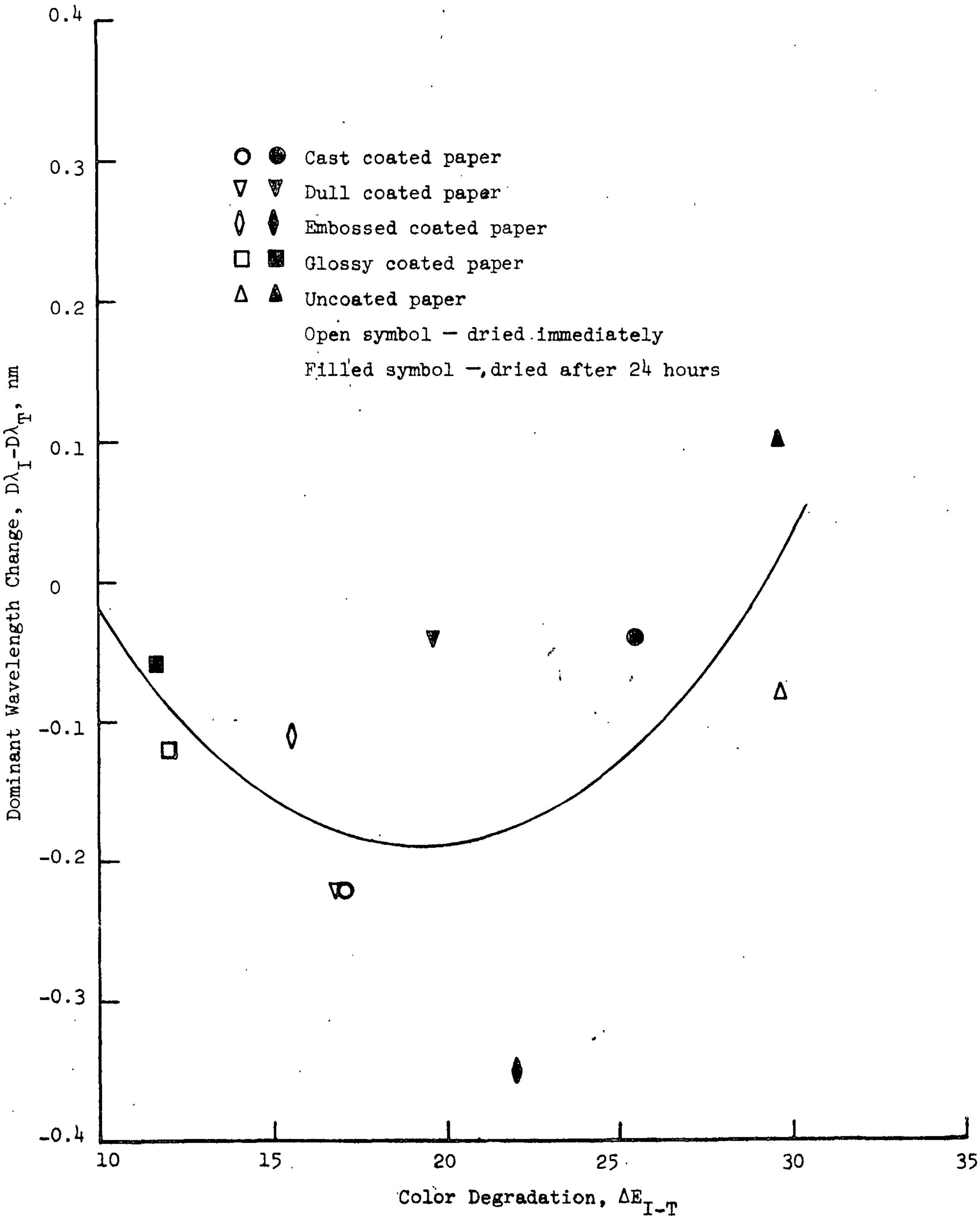

Figure 14. Correlation Between the Change in Dominant Wavelength, $D\lambda_I-D\lambda_T$, and the Color Degradation, ΔE_{I-T}, for Cyan Prints

due to external reflection the choice should be made on the basis of the ease with which each can be determined. Calculation of $\underline{P}_{\underline{I}}-\underline{P}_{\underline{T}}$ requires full colorimetric data. In contrast $\underline{Y}_{\underline{E}}$ can be determined by reflectance measurements through a single filter.

The color difference $\Delta\underline{E}_{\underline{I}-\underline{T}}$ data can also be used to evaluate the utility of other parameters for predicting color degradation by external reflection. It is commonly assumed that printed gloss is a good measure of the extent to which surface reflection is excluded from the viewing angle. Figures 15 and 16 are plots of 75° printed gloss against $\Delta\underline{E}_{\underline{I}-\underline{T}}$ for the magenta and cyan prints. Comparison with Fig. 9 and 12 reveals that it is far inferior to $\underline{Y}_{\underline{E}}$ as an indicator of color degradation. PSE has been proposed by Preucil (2) as a measure of the suitability of papers for color printing. Figures 17 and 18 are plots of PSE against $\Delta\underline{E}_{\underline{I}-\underline{T}}$ for the two sets of prints. If only the prints which were allowed to stand for 24 hours before drying are considered, there is a correlation between PSE and $\Delta\underline{E}_{\underline{I}-\underline{T}}$ but PSE is far inferior to $\underline{Y}_{\underline{E}}$ for predicting color degradation. For prints which were dried immediately after printing PSE is of little value.

Although $\underline{Y}_{\underline{E}}$ provides a good estimate of color degradation by surface reflection it is not presented at this time as the ultimate choice. It may prove better for routine measurement to use filters which are complementary to the ink colors such as the red, green, and blue filters commonly used in the Graphic Arts Industry for measuring color density. An external reflectance measured through such a complementary filter would detect only the light which the ink should ideally absorb and which would have the greatest effect upon color purity.

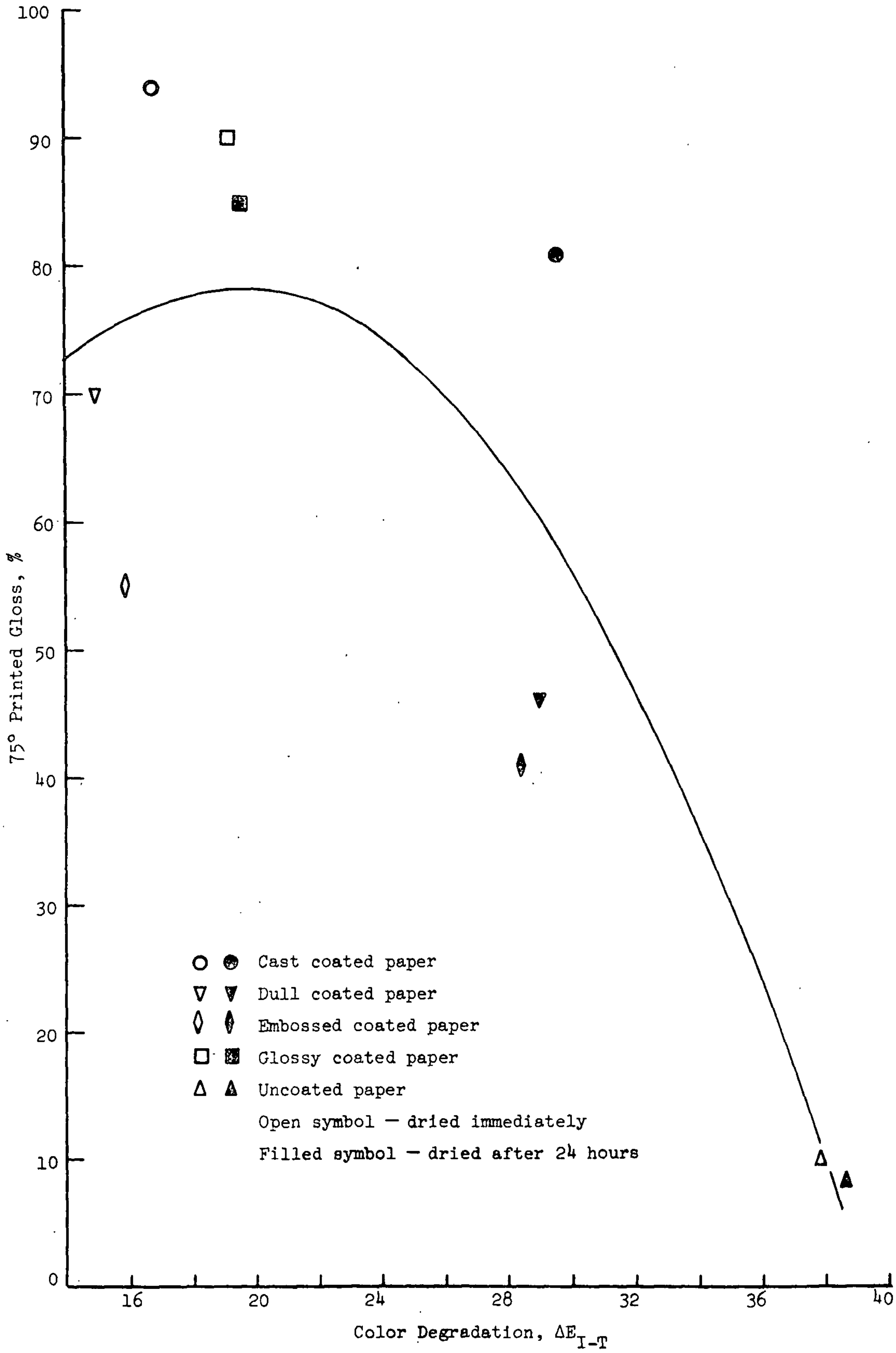

Figure 15. Correlation Between 75° Printed Gloss and Color Degradation, ΔE_{I-T}, for Magenta Prints

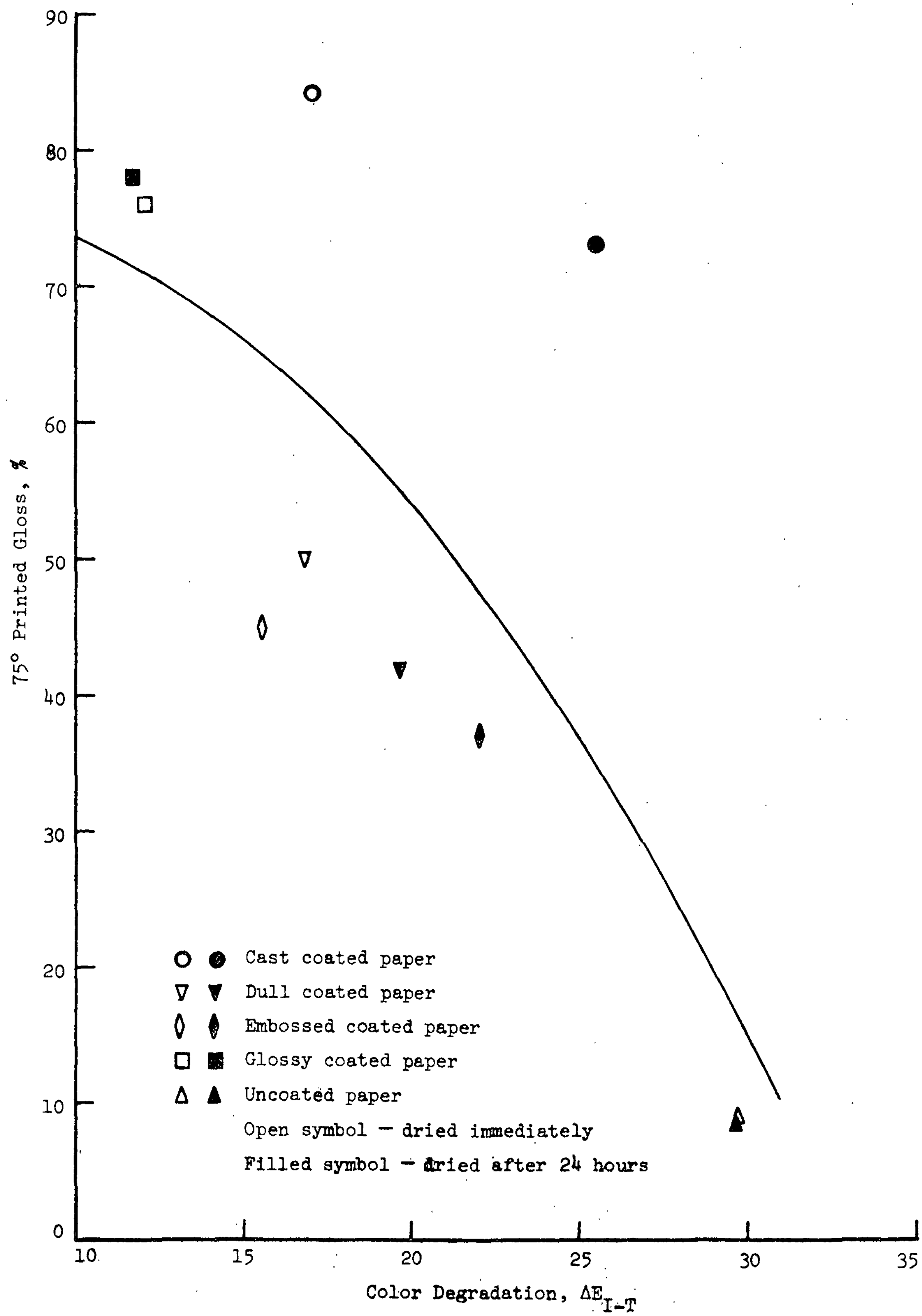

Figure 16. Correlation Between 75° Printed Gloss and Color Degradation, ΔE_{I-T}, for Cyan Prints

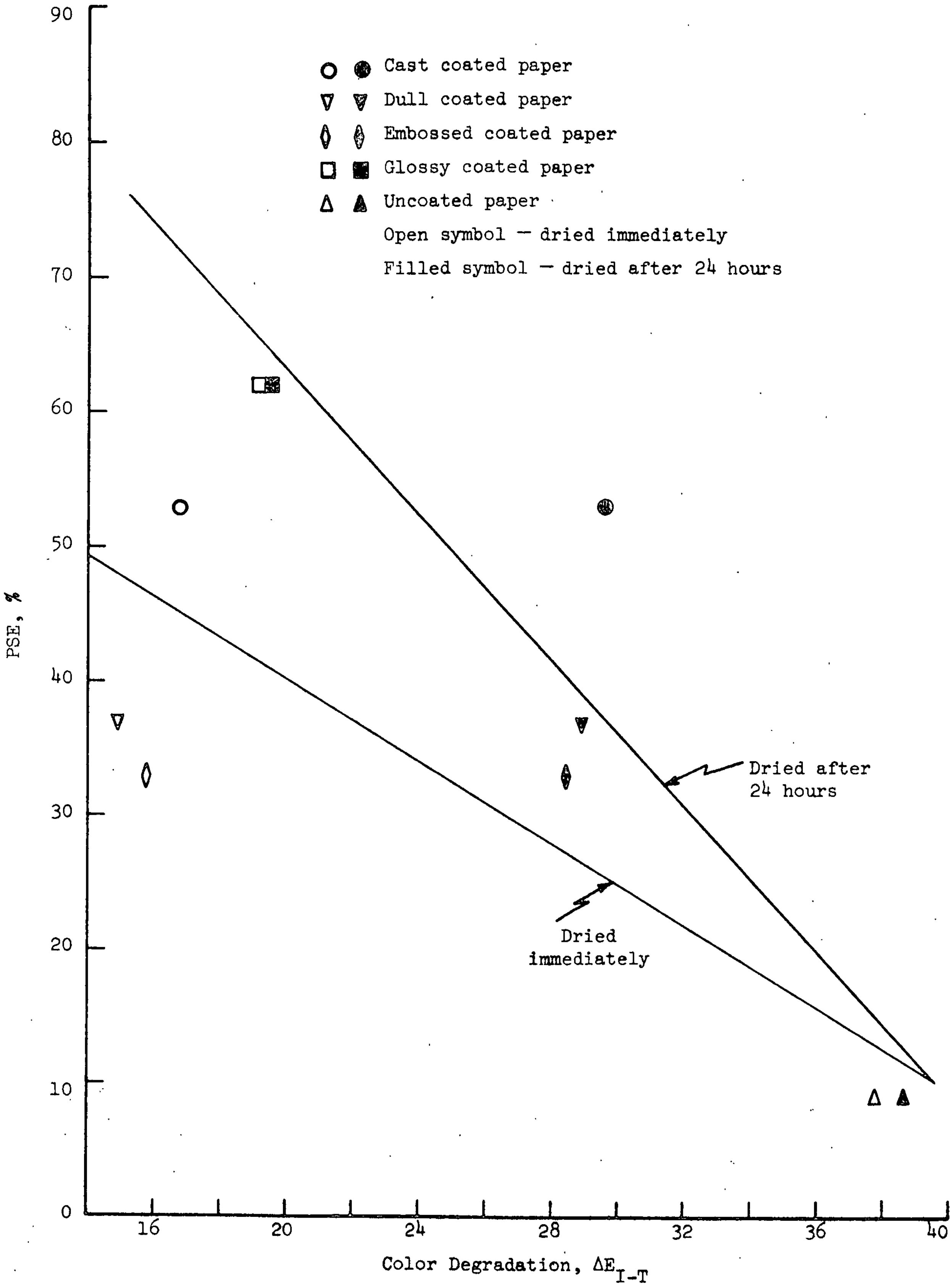

Figure 17. Correlation Between PSE and Color Degradation, ΔE_{I-T}, for Magenta Prints

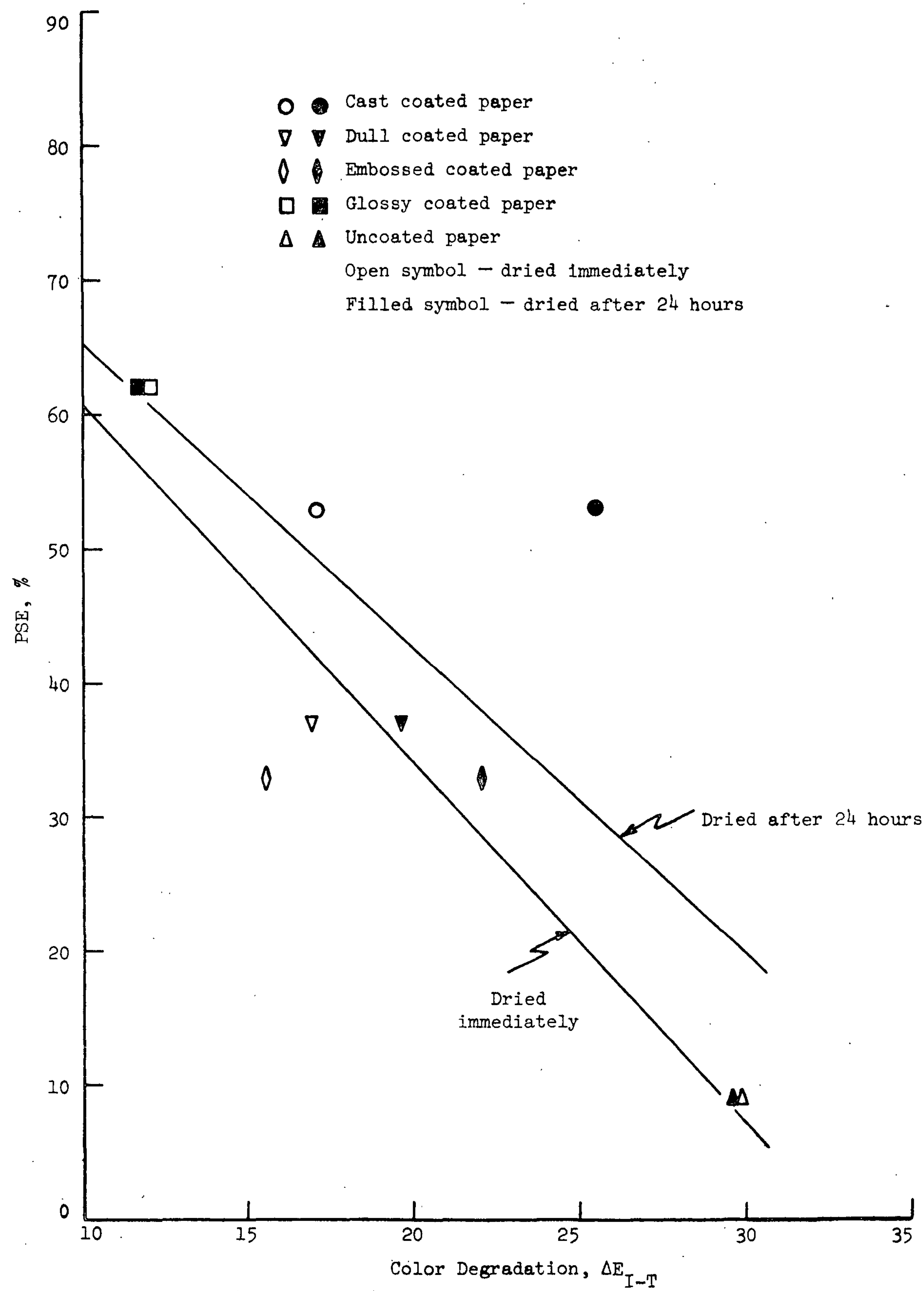

Figure 18. Correlation Between PSE and Color Degradation, ΔE_{I-T}, for Cyan Prints

REQUIREMENTS FOR A NEW INSTRUMENT

The data which have been presented are the result of twelve individual measurements ($I_{\perp\perp}$, $I_{\perp\parallel}$, $I_{\parallel\parallel}$ and $I_{\parallel\perp}$ with each of 3 different colorimetric filters). Furthermore each measurement was time consuming because the memory of the photoconductive receptors necessitated waiting for extended periods after balancing the bridge to insure that a stable balance had in fact been attained. This laborious procedure severely limited the amount of research data which could be collected and would preclude routine use of the instrument regardless of how well the significance of the data could be demonstrated. Furthermore, comparison of colorimetric data for cyan prints with that obtained with the Standard Brightness Tester raised questions regarding the accuracy of data. Therefore it was decided to design a new instrument which could provide research data and in addition serve as the prototype of an instrument for more general use.

Both the instrument design and the computation could be greatly simplified if incident light of only a single polarization plane could be used. Perpendicularly polarized light would be preferred because it is somewhat more strongly reflected from the surface and would therefore provide a stronger signal for detection of the external component. Therefore the colorimetric data for the magenta prints were recalculated using only the values obtained with perpendicularly polarized incident light and these new data were compared with data previously calculated using values for both incident polarizations. Comparative values for luminous reflectance, purity and dominant wavelength are displayed in Table IV in the Appendix. Because of the greater external reflection of perpendicularly polarized light, $\underline{Y_E}$ for the single polarization is somewhat increased and $\underline{Y_I}$ is decreased. The net change in $\underline{Y_T}$ shows a slight decrease for coated papers and a small increase for uncoated papers. Total purity, $\underline{P_T}$, decreases slightly upon restriction to the single incident polarization.

ΔE_{I-T} and Y_E both increase so that on a plot such as Fig. 9 the points fall on or near the same line. Therefore, although the numbers are slightly different, the prediction of color quality is equally as good. Therefore it was concluded that the utility of the instrument would not be impaired by restriction to this single incident polarization. It was further decided that the information obtained by varying the angle of incidence was not of sufficient value to justify this complicating feature in the new instrument. The choice of 45° incidence corresponds to viewing geometry which is widely used and is a good single angle for simulation of illumination under "average" viewing conditions.

It was decided that the CIE system should be retained because its basis on visual sensation permits evaluation of the visual importance of color differences and the ease with which it deals with additive color synthesis from component reflectances. However, it was anticipated that complementary filters, such as are used by the Graphic Arts Industry, may be better adapted to routine measurements. Therefore it was decided to provide for both sets of filters.

II. DESIGN OF A DIRECT READING POLARIZING REFLECTOMETER

DESCRIPTION OF INSTRUMENT

The design of the new reflectometer is shown schematically by Fig. 19. Polarization of the incident light is accomplished with a Rochon prism as previously described in Report One. The reflected light passes through an air spaced double calcite prism which acts as a beam splitter, transmitting the component corresponding to the incident polarization and reflecting the other component at an angle. Such a polarizing beam splitter has been used by Bryntse and Norman (5) although they were interested in specular rather than nonspecular reflectance. The reflected component is then reflected by a front surface mirror along a path parallel to the transmitted beam. Both beams pass through colorimetric filters, mounted in filter wheels, and are detected by silicon photodiodes. The photodiode outputs are processed by a pair of solid-state amplifiers. The corresponding signals from the two amplifiers may be mixed directly in the output amplifier to provide a signal proportional to the sum of the light fluxes detected by the two photodiodes which is the total reflectance. Alternatively the signal due to depolarization can be inverted without gain before mixing in the output amplifier to provide a direct reading of the reflectance difference which is the external reflectance. Therefore the total reflectance or the external reflectance can be obtained directly with the digital voltmeter, depending upon the position of Switch $S_{||}$. The internal reflectance must be calculated by subtraction of the external reflectance from the total reflectance. Provision is also made to switch off the signal from either first stage amplifier to read the other signal directly.

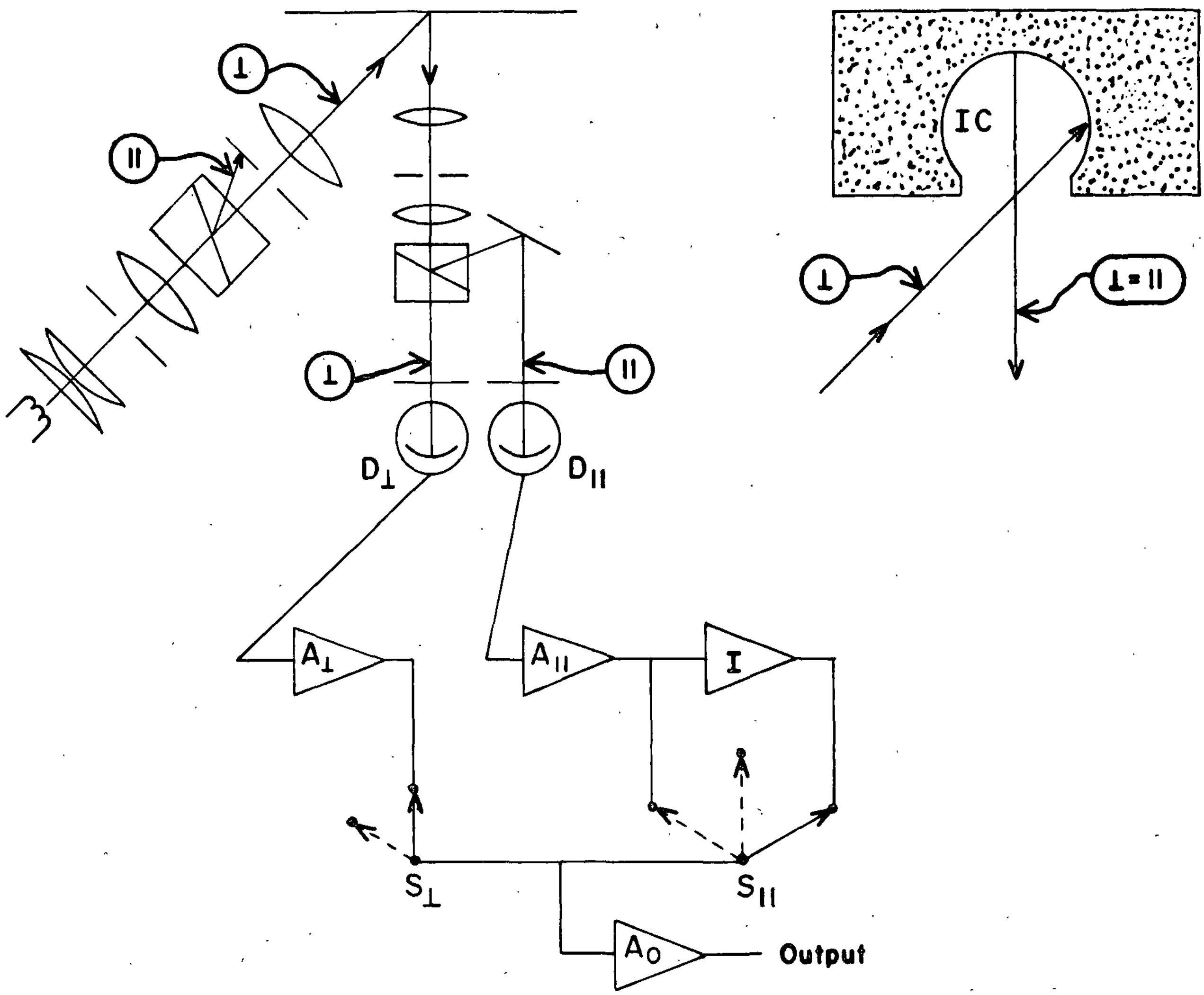

Figure 19. Schematic Diagram of the Direct Reading Polarizing Reflectometer. $D_{\perp}$ and $D_{\parallel}$ are Photodiodes Detecting the Perpendicular and Parallel Polarized Beams, Respectively. $A_{\perp}$ and $A_{\parallel}$ are First Stage Amplifiers for These Detectors. A_o is the Output Amplifier and I is a Signal Inverter. The Position of Switch $S_{\parallel}$ Determines Whether the Signal is Inverted. IC is the Integrating Cavity

It is essential that the gain of the two first stage amplifiers, $A_{\perp}$ and $A_{\parallel}$ be balanced to provide the same level of signal for completely depolarized light. Depolarized light may be provided by turning off the incident light and illuminating an opal glass surface in the sample position by transmission using an auxiliary light source. However, it is more convenient to use the incident source with the integrating sphere cavity shown as IC in Fig. 19. This integrating cavity is machined from compacted $BaSO_4$ powder. The incident beam strikes the cavity wall outside the viewing area of the receptor optical system so the light is effectively depolarized by multiple reflection. With either source of depolarized light the first stage amplifiers are adjusted to provide a zero difference signal. The gain controls of both first stage amplifiers are then locked and Switch $S_{\|}$ is positioned to bypass the inverter. The output amplifier gain is then adjusted to provide the correct total reflectance of a reflectance standard.

There are two parallel filter wheels each with ten holes arranged in two concentric circles such that a pair of filter holes on the same radial line is in position in the optical systems at one time. There is a pair of open holes in each filter wheel through which the light beams pass when the filters in the other wheel are used. One filter wheel carries filters tailored to provide the $X_{(red)}$, $X_{(blue)}$, $\underline{Y}$ and $\underline{Z}$ responses of the CIE system. The method for selection of these filters was described in Report One. The other filter wheel carries the Red (Wratten 25), Green (Wratten 58) and Blue (Wratten 47) filters which are complementary to the ink colors and are commonly used for color density measurements.

The completed direct reading polarizing reflectometer, including the voltmeter which provides digital reflectance values is shown in Fig. 20.

TEST OF POLARIZING EFFICIENCY

A fixture was provided to hold a microscope cover glass in a plane which intersects the sample plane at 22 1/2° in order to reflect incident polarized light directly into the receptors optical system. The output voltages corresponding to $I_{\perp\perp}$ and $I_{\perp\|}$ were 1.698 and 0.003 volts, respectively, or a ratio of 1.76×10^{-3}. This indicates that errors due to incomplete polarization of incident light will be negligible.

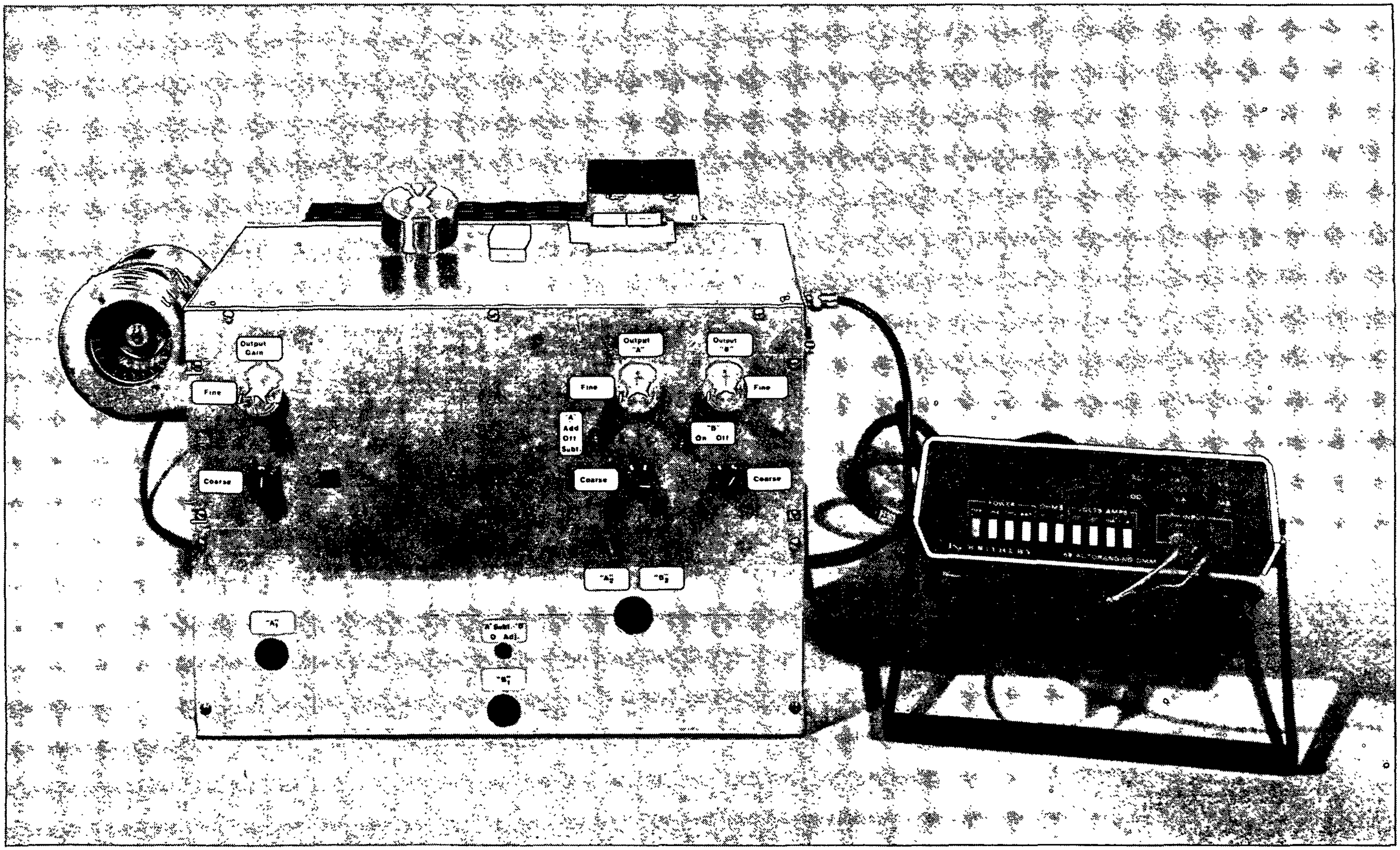

Figure 20. The Direct Reading Polarizing Reflectometer

III. PRELIMINARY MEASUREMENTS WITH THE DIRECT READING POLARIZING REFLECTOMETER

A comparison of the luminous reflectance data obtained with the new instrument with comparable data obtained with the standard brightness tester for the magenta prints previously studied is shown in Fig. 21. A plot of the corresponding purity data is shown in Fig. 22. These data are not comparable to that obtained earlier because of color changes that occurred during the intervening 7 months. These changes were documented by changes in the brightness tester color data but were not accompanied by detectable changes in printed gloss. The luminous reflectance values obtained with the new instrument for prints on coated papers are lower because of the single polarization plane of incident light as was expected. Agreement between the new instrument and the brightness tester with regard to purity data is excellent.

Figures 23 and 24 are plots of Y_E and P_I-P_T against the color degradation due to external reflection, ΔE_{I-T}. As was to be expected from work with the previous instrument, either of these quantites would satisfactorily predict the extent to which color is degraded by surface reflection. The direct reading feature of the new instrument now makes the determination of Y_E no more difficult or time consuming than the determination of printed gloss which has been shown to be an unreliable indicator.

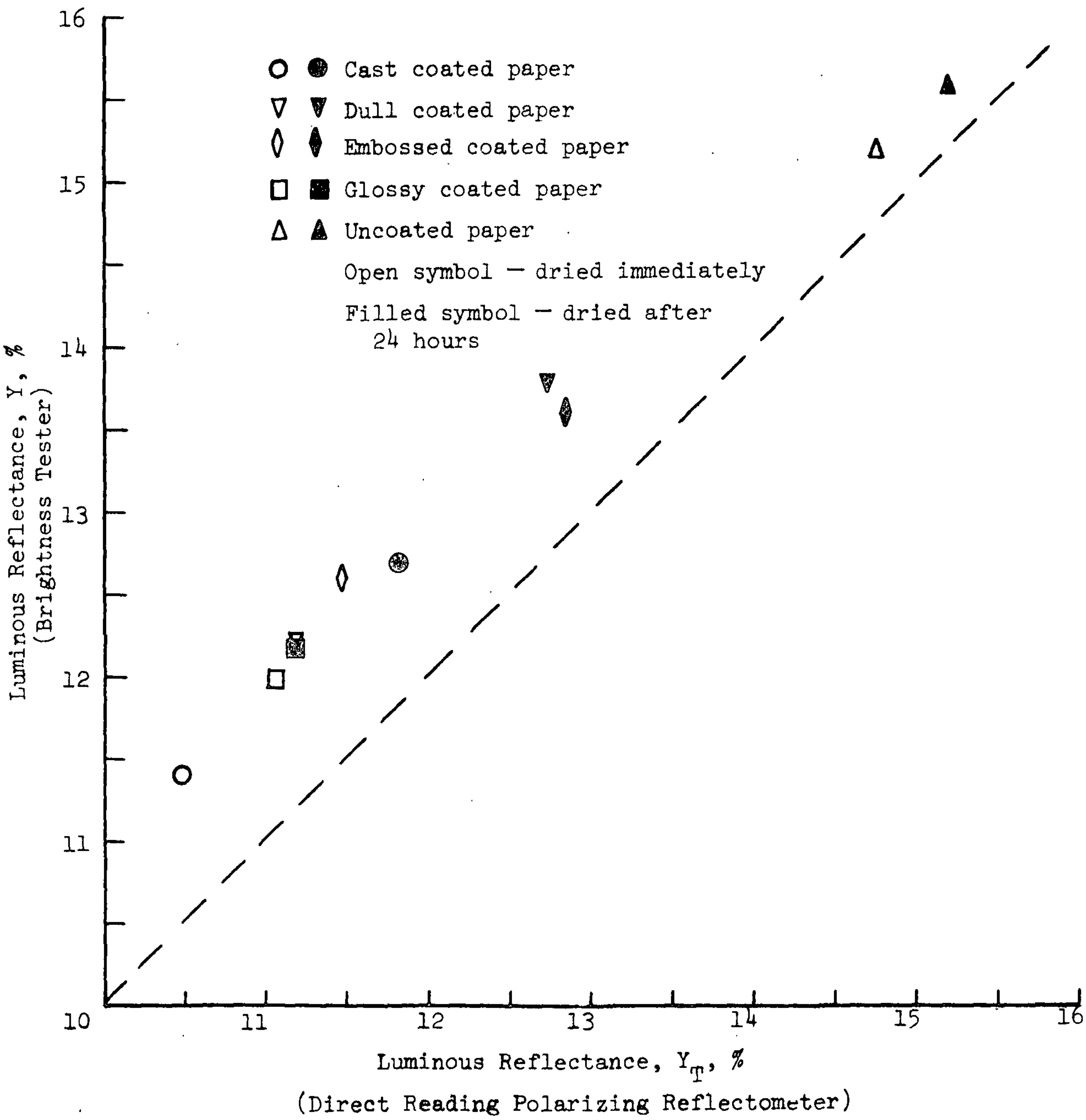

Figure 21. Magenta Print Luminous Reflectance. Comparison of Direct Reading Polarizing Reflectometer with the Brightness Tester

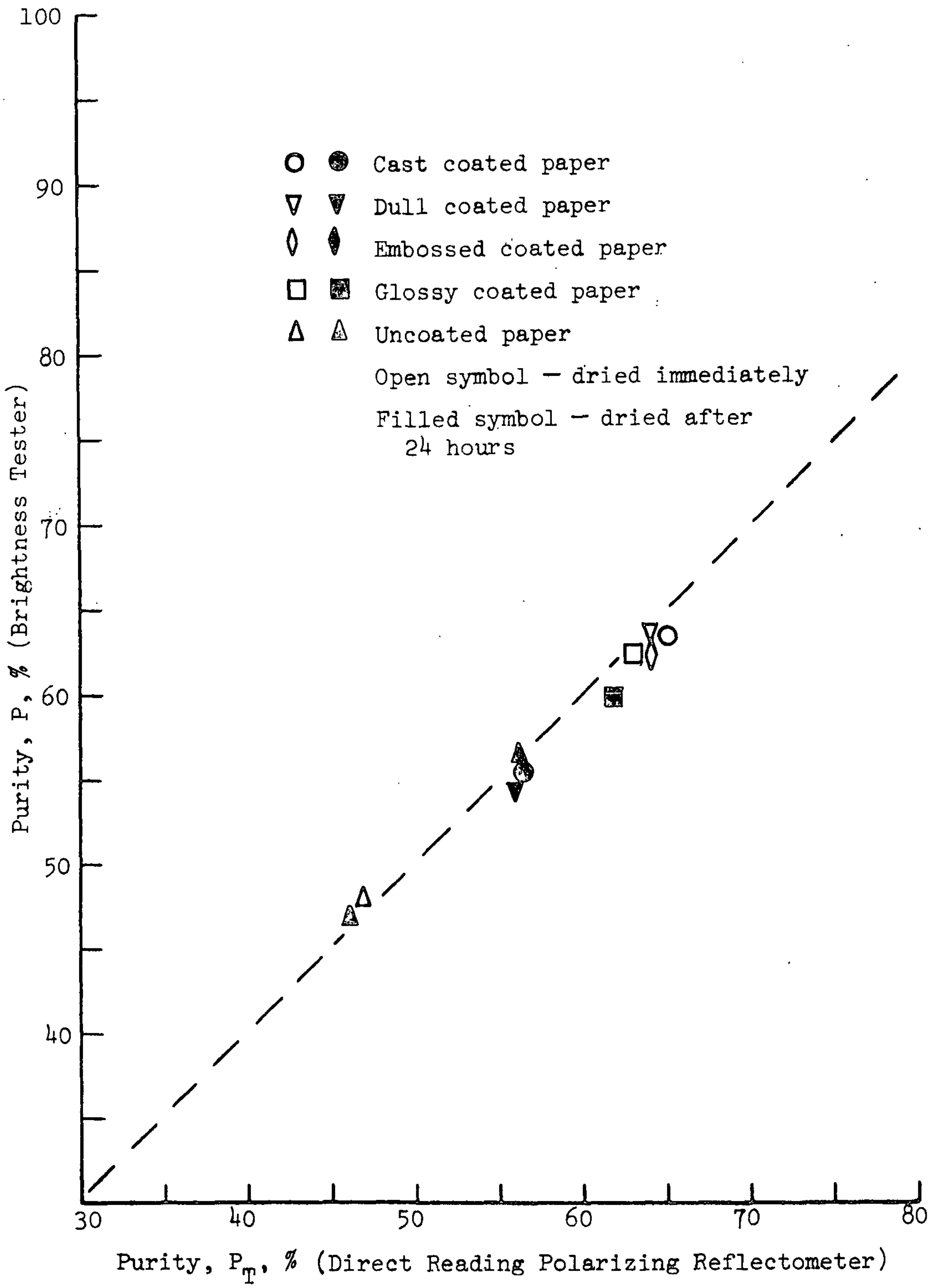

Figure 22. Magenta Print Purity. Comparison of Direct Reading Polarizing Reflectometer to the Brightness Tester

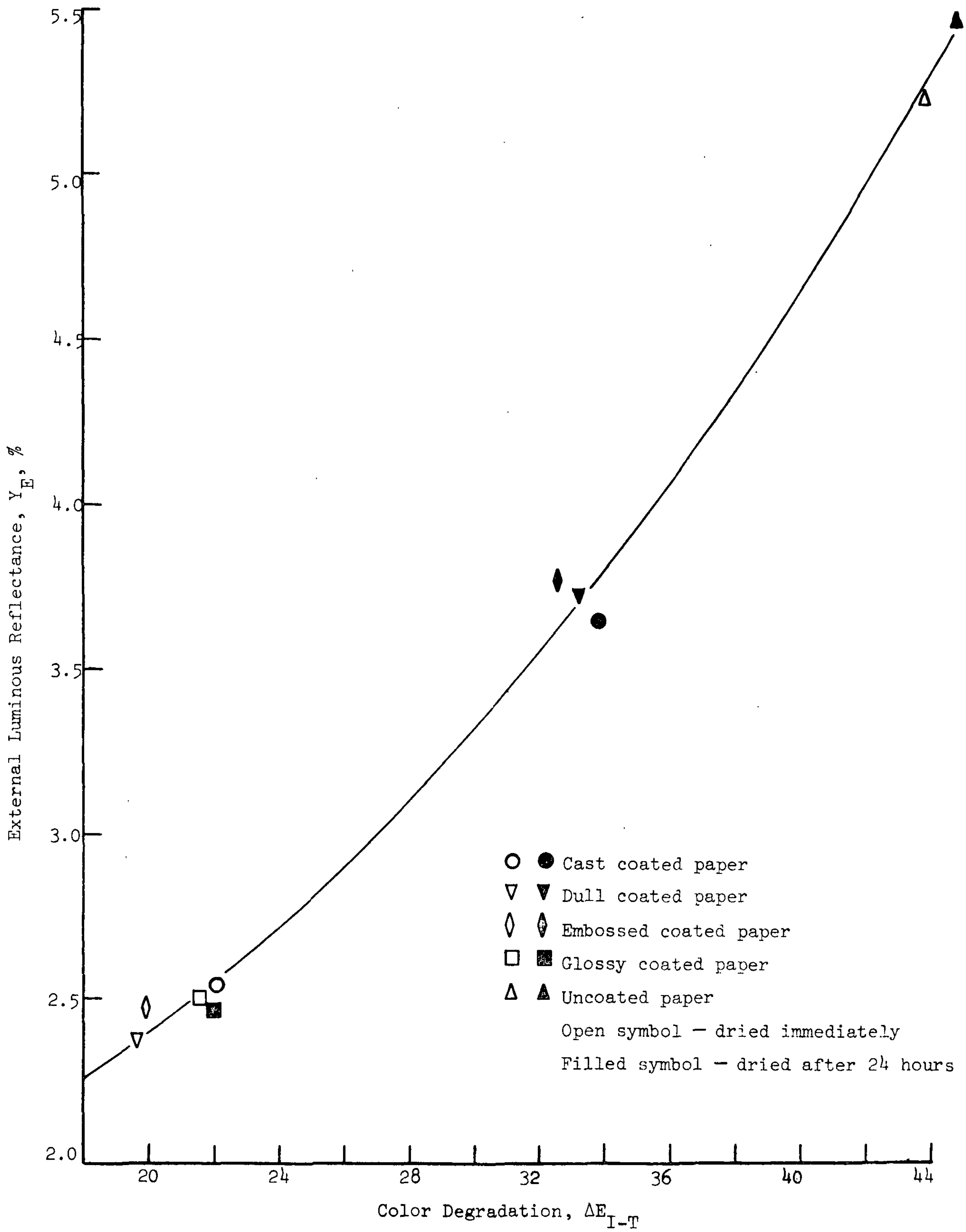

Figure 23. Correlation Between the External Luminous Reflectance and the Color Degradation, ΔE_{I-T} for the Magenta Prints as Determined with the Direct Reading Polarizing Reflectometer

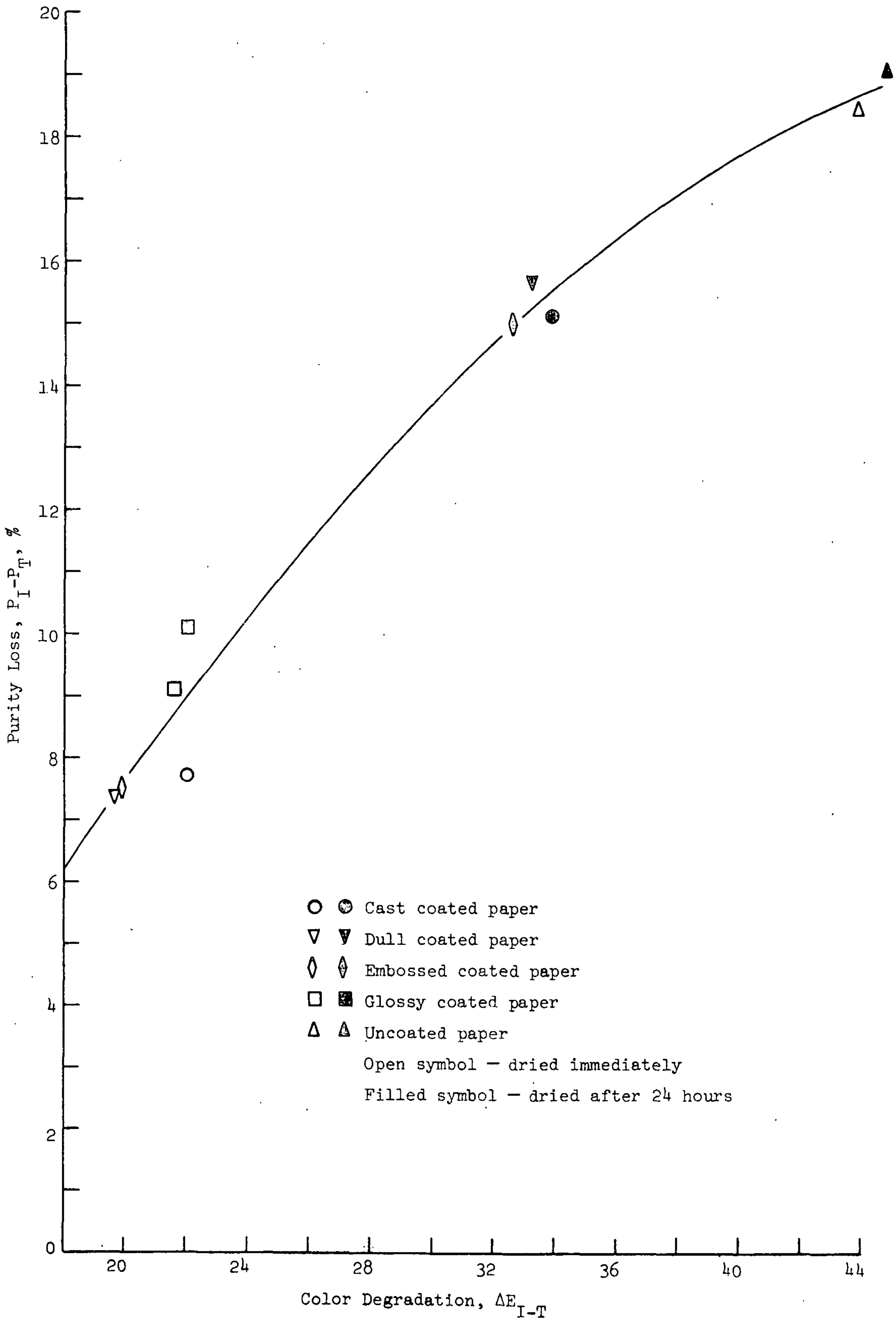

Figure 24. Correlation Between the Purity, Loss, P_I-P_T, and the Color Degradation, ΔE_{I-T}, for the Magenta Prints, as Determined with the Direct Reading Polarizing Reflectometer

FUTURE WORK

Future work under this project will be directed toward two objectives:

1. Improvement of the understanding of the effects of surface reflection on color, and
2. Selection of optimum methods of testing prints in the evaluation of papers for high quality color printing.

The improved understanding is necessary to insure that the test method selected will be appropriate for detecting all important color effects. The color difference ΔE_{I-T}, due to degradation of color by external reflection, will be resolved into components of dominant wavelength (hue), purity and lightness to determine the visual importance of the change in each of these directions. Prints on a wider variety of papers with four color process inks, including the important overprints, will be studied to determine the generality of these effects. The relationship between Y_E, which is directly measurable, and other changes in color will be examined to determine how generally reliable Y_E is for predicting total color degradation. External reflectance measured through complementary filters, which may be more closely related to loss in color purity, will be compared to Y_E as an indicator of color degradation by surface reflection.

ACKNOWLEDGMENTS

The counsel of Mr. Leonard Dearth of the Institute staff is gratefully acknowledged. Thanks are also due Mr. Wayne Shillcox who tailored the colorimetric filters to the required CIE responses.

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APPENDIX

TABLE II

DESCRIPTION OF PRINTS

	Paper	Color of Ink	Ink Weight, g/m^2 [a]	Interval Before Drying, hr [b]	75° Gloss, %
1	Cast coated	Magenta	2.52	0	94
1	Cast coated	Magenta	2.57	24	81
2	Dull coated	Magenta	2.55	0	70
2	Dull coated	Magenta	2.54	24	46
3	Embossed	Magenta	2.58	0	55
3	Embossed	Magenta	2.40	24	41
4	Glossy	Magenta	2.52	0	90
4	Glossy	Magenta	2.56	24	85
5	Uncoated	Magenta	2.50	0	9.9
5	Uncoated	Magenta	2.50	24	8.2
1	Cast coated	Cyan	2.41	0	84
1	Cast coated	Cyan	2.50	24	73
2	Dull coated	Cyan	2.58	0	50
2	Dull coated	Cyan	2.41	24	42
3	Embossed	Cyan	2.49	0	45
3	Embossed	Cyan	2.53	24	37
4	Glossy	Cyan	2.38	0	76
4	Glossy	Cyan	2.39	24	78
5	Uncoated	Cyan	2.39	0	8.9
5	Unocated	Cyan	2.53	24	8.5

[a] Amount of ink in g/m^2 transferred to the paper.
[b] Hours between printing and drying.

TABLE IIIA

COLORIMETRIC DATA FOR MAGENTA PRINTS

Paper Code	Interval Before Drying, hr[a]	Reflectance Component[b]	Polarizing Reflectometer of Report One: Luminous Reflectance, Y, %	Trichromatic Coefficient x	Trichromatic Coefficient y	Dominant Wave-length, nm	Purity, %	Color Difference ΔE	Standard Brightness Tester: Luminous Reflectance, Y, %	Trichromatic Coefficient x	Trichromatic Coefficient y	Dominant Wave-length, nm	Purity, %	Color Difference ΔE
1	0	I	8.22	0.572	0.252	493.9C								
		E	1.95	0.456	0.270	494.8C								
		T	10.17	0.551	0.256	494.0C	69.5	4.6	10.4	0.552	0.264	493.5C	66.2	3.43
1	24	I	8.12	0.580	0.253	493.8C								
		E	3.05	0.419	0.330	603.3								
		T	11.18	0.544	0.270	493.3C	62.4	14.8	11.4	0.544	0.277	492.9C	59.5	13.02
2	0	I	8.65	0.573	0.248	494.1C								
		E	1.80	0.458	0.272	494.5C								
		T	10.46	0.554	0.252	494.1C	71.6	0[c]	10.7	0.554	0.262	493.7C	67.6	0[c]
2	24	I	9.17	0.570	0.248	494.1C								
		E	3.26	0.409	0.340	596.6								
		T	12.43	0.537	0.267	493.6C	62.2	18.1	12.8	0.534	0.277	493.1C	57.9	19.05
3	0	I	9.31	0.567	0.246	494.3C								
		E	1.99	0.443	0.279	494.3C								
		T	11.30	0.547	0.251	494.3C	70.6	6.0	11.6	0.543	0.263	493.7C	64.9	7.47
3	24	I	9.25	0.567	0.248	494.1C								
		E	3.25	0.412	0.342	595.8								
		T	12.50	0.536	0.267	493.6C	62.0	18.7	12.6	0.536	0.274	493.2C	59.3	16.85
4	0	I	8.67	0.576	0.247	494.1C								
		E	2.20	0.439	0.301	670.5								
		T	10.87	0.552	0.256	493.9C	69.4	3.9	10.9	0.553	0.264	493.5C	66.4	2.08
4	24	I	8.81	0.579	0.249	494.0C								
		E	2.15	0.430	0.325	607.5								
		T	10.96	0.555	0.261	493.7C	68.2	5.9	11.0	0.556	0.270	493.2C	64.6	5.01
5	0	I	9.14	0.530	0.248	494.7C								
		E	4.31	0.386	0.332	598.4								
		T	13.45	0.492	0.270	494.0C	52.8	41.5	13.6	0.494	0.277	493.5C	50.0	39.75
5	24	I	9.39	0.528	0.247	494.8C								
		E	4.47	0.384	0.338	593.9								
		T	13.86	0.491	0.271	494.0C	52.1	43.3	14.3	0.489	0.275	493.7C	50.3	41.88
2 Laminated		I	8.78	0.593	0.248	493.9C								
		E	1.65	0.487	0.293	492.5C								
		T	10.43	0.579	0.254	493.7C	75.3	11.4	10.9	0.569	0.268	493.2C	67.8	6,96

[a]Hours between printing and drying.
[b]I = Internal reflectance; E = External reflectance; T = Total reflectance.
[c]All color differences are relative to this print which had the highest purity of the printed (but not laminated) samples.

TABLE IIIB

COLORIMETRIC DATA FOR CYAN PRINTS

Paper Code	Interval Before Drying, hr[a]	Reflectance Component[b]	Polarizing Reflectometer of Report One at 45° Incidence: Luminous Reflectance, Y, %	Trichromatic Coefficient x	Trichromatic Coefficient y	Dominant Wave-length, nm	Purity, %	Color Difference ΔE	Standard Brightness Tester: Luminous Reflectance, Y, %	Trichromatic Coefficient x	Trichromatic Coefficient y	Dominant Wave-length, nm	Purity, %	Color Difference ΔE
1	0	I	7.13	0.141	0.133	476.0								
		E	1.66	0.178	0.184	477.5								
		T	8.79	0.146	0.140	476.2	79.8	10.1	11.0	0.144	0.159	478.3	78.4	4.2
1	24	I	7.71	0.141	0.137	476.5								
		E	2.45	0.218	0.221	476.9								
		T	10.16	0.154	0.151	476.6	76.0	4.4	11.1	0.149	0.160	477.9	76.4	3.8
2	0	I	8.06	0.144	0.142	476.7								
		E	1.78	0.193	0.207	478.5								
		T	9.84	0.151	0.151	477.0	77.1	0[c]	11.4	0.147	0.162	478.3	77.0	0[c]
2	24	I	8.67	0.144	0.146	477.1								
		E	2.02	0.224	0.231	477.6								
		T	10.69	0.154	0.157	477.2	75.0	7.7	11.9	0.148	0.162	478.2	76.4	3.8
3	0	I	8.43	0.146	0.146	476.9								
		E	1.68	0.194	0.204	478.0								
		T	10.11	0.152	0.153	477.0	76.4	2.5	11.7	0.146	0.164	478.6	76.9	2.3
3	24	I	9.12	0.146	0.145	476.9								
		E	2.50	0.224	0.252	481.2								
		T	11.62	0.156	0.160	477.2	74.0	14.4	12.4	0.150	0.164	478.2	75.6	7.3
4	0	I	7.72	0.140	0.137	476.5								
		E	1.21	0.182	0.190	477.7								
		T	8.93	0.144	0.142	476.7	80.4	10.2	10.7	0.142	0.157	478.2	79.1	6.7
4	24	I	7.53	0.140	0.132	476.1								
		E	1.12	0.188	0.189	477.0								
		T	8.65	0.144	0.138	476.1	80.8	12.3	11.0	0.144	0.156	478.1	78.8	4.4
5	0	I	9.12	0.156	0.159	477.2								
		E	3.11	0.262	0.271	478.3								
		T	12.23	0.174	0.178	477.3	65.5	30.0	12.9	0.168	0.185	478.7	66.5	24.1
5	24	I	9.31	0.156	0.161	477.4								
		E	3.04	0.267	0.266	474.5								
		T	12.35	0.174	0.178	477.3	65.4	30.7	12.9	0.168	0.184	478.5	66.5	24.9

[a]Hours between printing and drying.
[b]I = Internal reflectance; E = External reflectance; T = Total reflectance.
[c]All color differences are relative to this print.

TABLE IV

EFFECT OF INCIDENT POLARIZATION PLANE UPON COLORIMETRIC DATA

			Perpendicular Plus Parallel Polarized Incident Light				Perpendicular Polarized Incident Light			
Paper Code	Interval Before Drying, hr[a]	Reflectance Component[b]	Luminous Reflectance, $\underline{Y}$, %	Purity, %	Dominant Wavelength, nm	Color Difference $\Delta\underline{E}_{(\underline{I}-\underline{T})}$[c]	Luminous Reflectance, $\underline{Y}$, %	Purity, %	Dominant Wavelength, nm	Color Difference $\Delta\underline{E}_{(\underline{I}-\underline{T})}$[c]
1	0	E	1.95	45.9	494.8C	16.8	2.08	50.3	495.6C	18.7
		I	8.22	74.7	493.9C		7.71	74.3	493.8C	
		T	10.17	69.5	494.0C		9.79	69.3	494.1C	
1	24	E	3.05	32.8	603.2	29.6	3.28	30.2	610.5	32.6
		I	8.12	76.2	493.8C		7.65	76.0	493.8C	
		T	11.18	62.4	493.3C		10.93	61.4	493.4C	
2	0	E	1.80	45.5	494.5C	14.9	1.92	48.7	495.2C	16.6
		I	8.65	76.6	494.1C		8.11	76.2	494.0C	
		T	10.46	71.6	494.1C		10.03	71.2	494.2C	
2	24	E	3.26	32.8	596.6	28.9	3.52	30.4	601.1	32.0
		I	9.17	76.0	494.1C		8.68	75.6	494.1C	
		T	12.43	62.2	493.6C		12.2	60.8	493.6C	
3	0	E	1.99	39.9	494.3C	15.8	2.12	36.5	494.4C	18.2
		I	9.31	76.4	494.3C		8.83	76.7	494.3C	
		T	11.30	70.6	494.3C		10.95	69.7	494.3C	
3	24	E	3.25	34.3	595.8	28.4	3.49	31.6	594.1	32.6
		I	9.25	75.5	494.1C		8.77	75.8	494.2C	
		T	12.50	62.0	493.6C		12.27	60.2	493.5C	
4	0	E	2.20	30.5	670.5	19.2	2.30	27.7	492.5C	22.0
		I	8.67	77.6	494.1C		8.17	78.0	494.1C	
		T	10.87	69.4	493.9C		10.48	68.4	494.0C	
4	24	E	2.15	34.4	607.5	19.6	2.25	30.4	608.4	22.2
		I	8.81	77.4	494.0C		8.33	77.5	494.0C	
		T	10.96	68.2	493.7C		10.59	67.0	493.7C	
5	0	E	4.31	24.4	598.4	37.8	4.90	23.6	601.0	42.8
		I	9.14	68.6	494.7C		8.84	68.0	494.7C	
		T	13.45	52.8	494.0C		13.74	50.7	494.0C	
5	24	E	4.47	25.7	593.9	38.7	5.09	25.0	595.5	43.9
		I	9.39	68.5	494.8C		9.09	68.1	494.8C	
		T	13.86	52.1	494.0C		14.18	49.9	493.9C	

[a]Hours between printing and drying.
[b]E = External reflectance; I = Internal reflectance; T = Total reflectance.
[c]Color difference between internal and total reflectance components.